TR-1337-3

SHIP ACQUISITION PLANNING

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report documents the current state of the Navy Ship Acquisition Planning Tool, developed for the Naval Material Command Acquisition Research Council under contract with the Office of Naval Research. The report discusses the structure of the acquisition tool, and describes in detail its major modules: the ship cost module, the yard price module, and the optimization module.

The ship cost module calculates the cost to a shipyard to build a ship, given unique ship and yard characteristics. The yard price module then calculates the price that the shipbuilder is likely to charge the Navy, based on the characteristics of the existing market. Finally, the optimization module calculates the lowest cost ship acquisition program, given the constraints specified.

An important feature of the acquisition planning tool is that it recognizes the commercial market existing in the United States shipbuilding industry. Commercial orders allow some shipyards to remain working with little or no Navy business. It is possible, in the future, to extend this work to predict commercial business in the face of world economic conditions and the world shipbuilding market.

The ship acquisition planning tool has been assembled and demonstrated as a working tool. The demonstration was completed using preliminary data, information and estimates obtained from interviews with knowledgeable people and other sources. These data were the best that could be developed

within the time constraints, access and scope under this contract. The information and research estimates were adequate to assemble and preliminarily demonstrate the tool. The next step is to validate this tool using updated and more current data on Navy shipbuilding programs. This will allow pinpointing specific yard characteristics, and identifying variables which may be redundant in the ship acquisition planning tool as currently realized. These data are shown in Chapter 4, as well as the places within the Navy where these data are available. The validation phase of the ship acquisition tool includes assembling the data in a useful form, not only for the ship acquisition planning tool, but for other studies which may be appropriate for guiding the Navy Acquisition Program. These data must be assembled if serious analyses of various alternatives are to be made using the ship acquisition planning tool as documented in this report, or indeed in any other way that is appropriate. Without these data, no meaningful analysis can be done which can lead to rational plans for the Navy's future ship acquisition plans. Given the small amount of data available now, this report has shown, based on simplistic estimates of shipyard characteristics, what results can be provided from the ship acquisition planning tool.

The Navy ship acquisition tool, as proposed and developed by TASC, can develop the lowest cost shipbuilding program in the face of various types of constraints, and it can show the cost of individual constraints or constraints in concert. The ship acquisition planning tool promises to be a significant advance in Navy ship acquisition planning.

The major problem facing potential users of the ship acquisition planning tool is that necessary data have not been made available. The data identified must be collected and assembled into a useful form, if any serious analysis is to be

done, whether or not the Navy chooses to continue with this particular ship acquisition planning tool or to work with any other ship acquisition planning tool.

The Navy is now facing a proposed large rapid buildup in the Naval force structure and it must deal with the beginning of this buildup in the face of a shipbuilding base which is in poor economic and technical health. The Navy, at present, has no planning tool with which to support the development of alternative programs. TASC's ship acquisition planning tool, along with all methods available or in prospect, can provide the necessary analytic support to assist Navy planners in making the proper choices.

Recommendation 1 - Assemble a data base documenting performance of shipbuilders in serving the Navy's shipbuilding program.

Recommendation 2 - Validate, refine and complete the development of the ship acquisition planning tool.

1. INTRODUCTION

1.1 BACKGROUND TO REPORT

This report forms a sequel to TASC's earlier reports[1] prepared for the Navy on "Planning for Navy Ship Acquisition". The earlier reports presented an overview of the shipbuilding industry, the economics of the industry, and the competitive allocation process. An analysis of Navy ship acquisition was performed which demonstrated that it was possible to plan an optimum allocation of ship construction to shipyards which would result in minimum cost for the Navy. This analysis was based on a detailed examination of the allocation process and shipyard behavior in the case of the Guided Missile Frigate (FFG) Program. Shipyard management were interviewed at both shipyards (Bath and Todd) to establish or confirm relationships between different elements of costing and pricing behavior. These relationships were not tested with actual data, but data needs and sources were specified.

Further work included the development of a procedure to specify the Navy's effective demand for ships and the development, programming, and preliminary application of the yard cost component of the ship acquisition planning tool. Additionally, a method of optimization was designed to minimize Navy cost over the plan period. The programming system structure for the ship acquisition planning tool was also

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[1] TR-1337, Planning for Navy Ship Acquisition, December, 1978 and TR-1337-2, Modeling Navy Ship Acquisition, December, 1979.

developed, and the planning approach validated through further interviews. The main handicap to testing the planning tool for ship acquisition was the lack of access to Navy data. Accordingly, preliminary analysis was undertaken using aggregated data, data obtained directly from interviews with shipyard personnel, and informed estimation. The hypothetical data set included the following variables: labor hours necessary to build the ship; yard backlog; overhead rates; number of shifts worked; learning factors; labor turnover rates; employment window effects; differential inflation rates (e.g., labor vs. materials); labor force experience; and percentage breakdown of total ship cost by labor, raw material, and government furnished equipment for an FFG-like program.

TR-1337-2 included a review of GFE costs, commercial work load, repair and conversion, the procurement process and contract form. This report describes the progress since made on developing and refining the ship acquisition planning tool, incorporating new data where possible and testing the planning tool's capabilities with selected problems. Also, commercial shipbuilding has been analyzed with respect to its interactions with Navy shipbuilding.

1.2 OBJECTIVE

The objective of the ship acquisition planning tool is to provide the Navy with a means of planning for ship construction in shipyards in a cost-efficient manner, given a number of such constraints as the maintenance of a certain number of shipyards in the defense industrial base. The idea is planned allocation, i.e., if selected yards bid then one would expect the yards to have specific costs, and in fact

the planned allocation would present a viable scheme for meeting the building requirements. Also, the feasibility of alternative shipbuilding programs can be tested.

In support of this objective, work has continued on Navy ship acquisition and has been expanded to incorporate commercial ship acquisition by including commercial production in the costing elements. Analysis has also been carried out for the overall commercial shipbuilding program, including subsidies, and the impact of such activity on naval ship procurement.

The results of this expansion of the ship acquisition planning tool are summarized as follows:

- <u>Estimation of yard costs</u> - The functional relationship used to adjust the initial manhour estimate has been modified. Two variables in the manhour estimate equation -- turnover rate and the rate of change of employment -- are now defined differently. Finally, a new variable representing worker distribution among shifts has replaced the number of shifts variable in both the manhour estimate and the overhead rate equation.

- <u>Determination of yard prices and Navy costs</u> - The approach used in TR-1337 and TR-1337-2 has been totally replaced because of technical difficulties. TASC's continued analysis of the Navy's ship procurement process resulted in an auction market methodology by which yard prices and Navy costs can be determined. Essentially, the procedure involves a determination of individual yard bids given an assumed allocation of ships to yards in a procurement period. Any arbitrary set of information can be used to determine a shipyard's bid for a particular ship: for example, a yard's bid may be

determined, in part, by the kind of commercial shipbuilding activity at that yard. Thus, a framework has been provided to take into account commercial shipbuilding activity insofar as it affects the costs of the naval shipbuilding program. The issue of commercial shipbuilding subsidies has also been analyzed with respect to naval shipbuilding costs.

1.3 CONTENT OF THE REPORT

The following chapters describe the progress and results to date of TASC's efforts to develop a ship acquisition planning tool. Chapter Two describes some factors relating to naval and commercial shipbuilding programs, including a consideration of commercial shipbuilding subsidies. Chapter Three provides the conceptual outline of the ship acquisition planning tool and its characteristics as developed by TASC. Chapter Four gives details on the data collection tasks which were successful in identifying sources of required data, but not successful in obtaining much of the data. Chapter Five gives the results of demonstrating the planning tool, using simple estimates derived from the sparse data on hand. Finally, Chapter Six brings together the conclusions and recommendations which have evolved from this work.

2. FACTORS RELATING TO SHIPBUILDING PROGRAMS

This chapter discusses some factors relating to naval and commercial shipbuilding programs. First, there is an elaboration of the technical difficulties associated with the approach previously recommended for estimating the yard prices for Navy ships[1]. The new approach, which circumvents these problems, is described next. Several characteristics of commercial shipbuilding are then presented: U.S. fleet composition, Maritime Administration programs, some differences between commercial and naval shipbuilding, costs of ship construction, and U.S. shipbuilding with respect to foreign competition. This is followed by a description of how the impact of commercial shipbuilding is presently incorporated in the ship acquisition planning tool. Finally, the effects of commercial shipbuilding subsidies are discussed, in general terms and with respect to naval shipbuilding.

2.1 ESTIMATING YARD PRICES: DIFFICULTIES AND APPROACH

The most difficult industry to model in economics has been one with a small number of sellers. A reasonably satisfactory theory of the polar cases of competition and discriminatory monopoly has long been the common property of the economics profession. The elegance of the theories of competition and discriminatory monopoly arises in large part from the fact that in each case we can ignore the action of rivals. Under competition we can neglect the interrelations among firms

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[1] The previous approach to yard price estimation is described in TR-1337 and TR-1337-2.

because each firm is an insignificant part of the whole and what it does can be assumed to have no effect upon its rivals. Under a monopoly, there are no close rivals, so again we do not have to deal with any sort of interrelations. However, competition among the few (an oligopoly situation) raises a particularly difficult issue: what does a firm assume that its rivals will do when it changes price? There are an arbitrarily large number of possibilities and economists have made very little progress over the last one hundred and fifty years in narrowing these possibilities on a priori grounds.

A further complication of applying these economic theories to the shipbuilding industry is that there are many segments in the industry. For example, there may be only two yards which are capable of building Tridents for the Navy, but there may be five or six which can build FFGs.

Let us assume that we can locate ship types along a unit line segment which measures complexity of the undertaking. Each of the firms in the industry has the technical ability at a point in time to compete in a portion of the line segment. We picture this situation in Figure 2.1-1 with 6 yards.

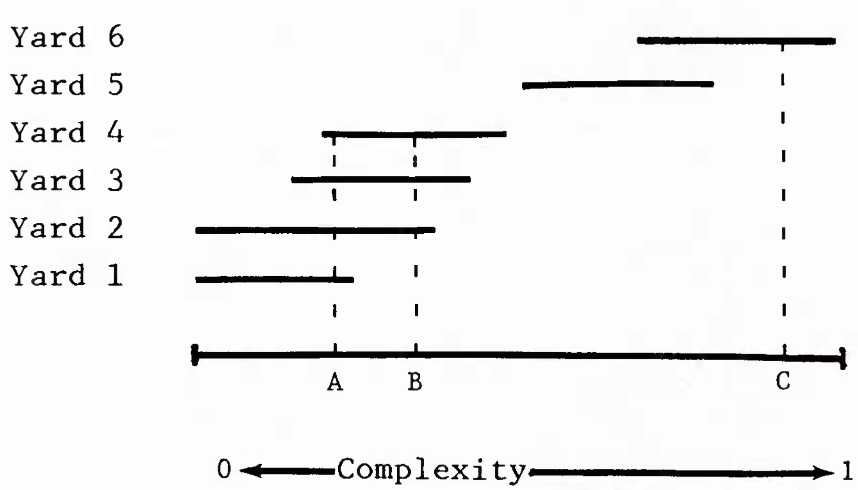

Figure 2.1-1 The Firms in the Industry by Complexity of Ship.

Ship type A has four yards technically equipped for construction, type B has three yards, and type C has only one.

Strictly speaking this means that technical consideration can impose an increased oligopoly problem for each ship type. Thus, the severity of the oligopoly problem may depend critically on the specific type of ship. There are several other considerations related to specific ship type: some segments of the market may be more costly for the yards than others; a yard not normally competitive on a specific ship type may well bid if it knows that its lower cost rivals have already exhausted their capacities; and, over time yards make decisions to invest in capital equipment which can either enhance their ability to compete in a particular segment or widen the number of segments in which they can compete.

For example, these investment decisions require the firms to make forecasts about the specifics of the market for years ahead. If they are able to look deep into the future with a small error, they may well invest in a very specialized productive capacity. If they believe the future is clouded with risk, they may well diversify their productive capability. Using the notion of the complexity of a ship again, we may represent these two situations by drawing the relative cost of different ship types for each investment strategy (see Figure 2.1-2).

In particular, we note the impact of these alternative investment strategies on the relative cost of ship type B. This illustrates how the competitiveness of a specific ship type is sensitive to the investment strategy of the yards, which in turn is sensitive to the ability of firms to forecast the future demand for a given ship type.

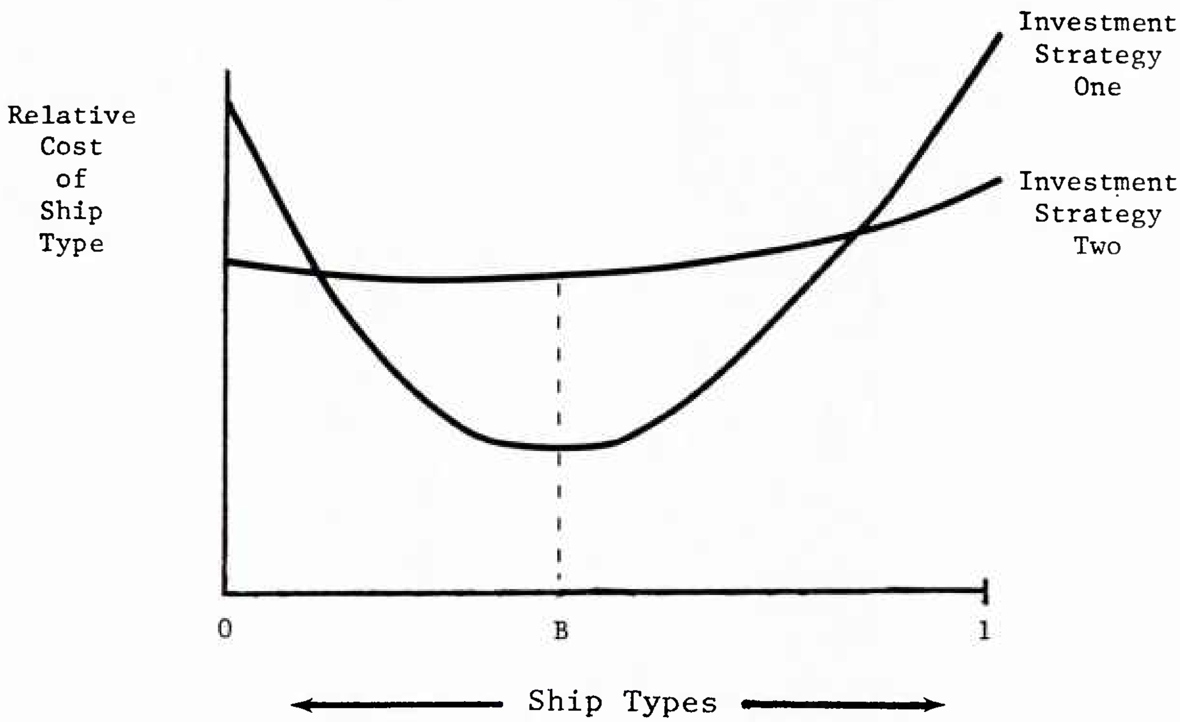

Figure 2.1-2 Relative Cost of Ship Types For Different Investment Strategies

All of this has a very clear implication: there is very little prior theoretical guidance by which to model the supply forces in such an industry. We cannot easily find a set of functional relations which specify the supply forces. Thus, the approach previously developed proved inappropriate.

We decided to circumvent the difficulties of supply-demand modeling by focusing on the market framework to capture the mechanics of an auction-market. We first decomposed the problem of yard price estimation into two parts: yard bid estimation, and yard price estimation through an auction market model. A relevant set of information can be chosen to determine a yard's bid for a particular ship: this is the key concept underlying TASC's new approach to determining yard prices

and costs to the customer. Interrelations among yards for a specific ship over time and other determinants of bids such as the effects of commercial shipbuilding can all be taken into account for yard bid determination. However, regardless of what set of complicated interrelations determine a firm's offer to produce a ship of a given type, the auction market framework provides a solution technique for estimating yard prices and customer costs given the various yard bids.

The auction market model in TASC's present form of the planning tool is briefly described in Chapter 3 and additional details are provided in Appendix B. Presently, the basic yard bids for a given allocation of ships to yards are determined on the basis of the yard objective functions (e.g., profit maximization, cash flow maximization). The final yard prices are determined through the mechanics of an auction market which estimates actual yard prices for particular ships on the basis of the bidding environment described by combinations of the following variables: sole source or multiple procurement; competitive or non-competitive ("allocated") procurement; if competitive, whether or not any yard "buys in". It should be noted that whether or not a yard "buys-in" is an input specified by the user (of the planning tool) on the basis of the bidding history of the yard in question.

While the difficult problem of estimating complex inter-firm price relationships has thus been obviated in this study, it is important to note that the new methodology allows the incorporation of these and other considerations in the bid determination process.

2.2 INCORPORATION OF COMMERCIAL SHIPBUILDING IN THE PLANNING TOOL

In the present form of the planning tool, the effects of commercial shipbuilding on naval shipbuilding costs are incorporated indirectly in two modules. First, in the yard cost estimation module, the commercial workload at any yard building Navy ships is entered as part of the backlog at the yard. The yard backlog affects the overhead rate[1] and influences the naval shipbuilding costs accordingly. Second, in the optimization module[1] of the planning tool, each yard building Navy ships is capacity-constrained in the number of Navy ships it can have under construction: this capacity constraint is determined both by the physical plant capacity and labor resources on hand, <u>and</u> by the level of commercial shipbuilding activity at the yard. The immediate natural question is whether or not commercial shipbuilding effects on naval shipbuilding can be taken into account directly.

As pointed out in Section 2.1, the new approach to yard price estimation does provide a framework for directly taking into account the commercial shipbuilding program. A yard's bid for a particular Navy ship may be based, in part, on the level of commercial shipbuilding activity at that yard. However, the existence or non-existence of such causal relationships between a yard's commercial activity and its bids for Navy ships can only be examined through extensive empirical analysis which would require significant resources beyond

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[1] TR-1337, TR-1337-2 and Chapter 3 of this report.

the scope of this study. It should be noted that such analysis would also determine the effects, if any, of naval shipbuilding on commercial shipbuilding costs. Although the effects of commercial shipbuilding activity on bids for Navy ships remain to be ascertained, the modular nature of the planning tool's price estimation process will allow incorporation of these and any other bid determinants with relative ease.

2.3 COMMERCIAL SHIPBUILDING SUBSIDIES AND RESOURCE MOBILITY

Much of the commercial shipbuilding subsidization program is justified on two grounds: first, it makes sense to invest in a reserve productive capacity; and second, commercial shipbuilding subsidies draw additional resources into the industry. There appears to be general agreement that investing in productive capacity is beneficial. Here we address only the issue of resources flowing into the industry.

It is important to recognize that there are situations where a subsidy program is simply a rearrangement of given resources, and will not increase the net productive resources in the industry. Such a situation is pictured in Figure 2.4-1. Assume that a fixed supply of resources is available to the industry. A government subsidy policy causes the demand for these resources to shift upwards and thus will only increase the price paid for these resources.

The existence of such cases has long been known in the economics profession. Nonetheless, this insight has somehow been lost in popular discussions. For example, current studies of the rising cost of medical care often omit the role of government and private insurance. In a market where resources are fixed by state restrictions on entry, insurance reduces the

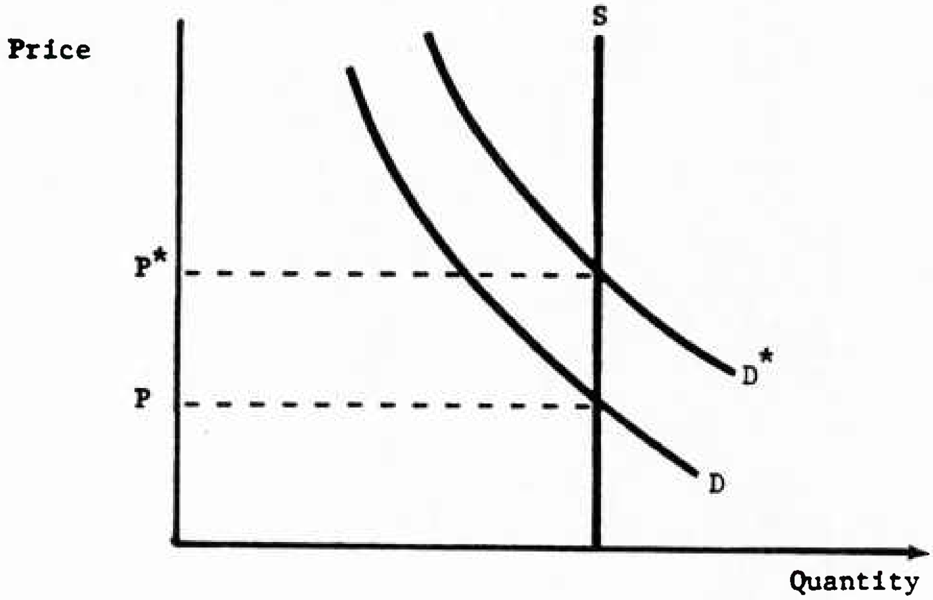


Figure 2.3-1 An Industry With Both Fixed Resources and a Government Subsidy

D - Demand for the goods, private

D* - Demand for the goods, private plus government subsidy

S - Fixed supply of the goods

P - Competitive price with private only demand

P* - Competitive price with private demand enhanced by a subsidy

private cost of medical care for those covered and drives up the cost for those who are not covered. In shipbuilding, a subsidy that simply raises resource prices in this fashion would be singularly perverse since government subsidization of the commercial market would directly increase the cost which the Navy pays. It should be noted that for shipyards operating below capacity, an increase in demand (and hence in the number of ships being built) results in a decrease in the average fixed cost, which leads to a lower price than would be expected through the simple analysis shown in Figure 2.4-1.

It is important to note that there are no obvious legal restrictions to employment in the shipbuilding trade comparable to the legal restrictions in the practice of medicine. It therefore seems reasonable to believe that the long run supply curve of resources, human and non-human alike, has a gently upward sloping shape, as drawn in Figure 2.4-2. For shipbuilding, the supply of resources comprises the acquisition of capital and labor, and the training of that labor. The long run supply is, typically, the supply of such resources over 2 to 3 years.

The effects of commercial shipbuilding subsidies follow from Figure 2.4-2: first, the subsidies provide the country with the additional capacity which produces the extra amount of ships, $Q^* - Q$; second, since costs of shipbuilding resources rise as a result of the subsidies, naval shipbuilding costs can be expected to increase during times of peace.

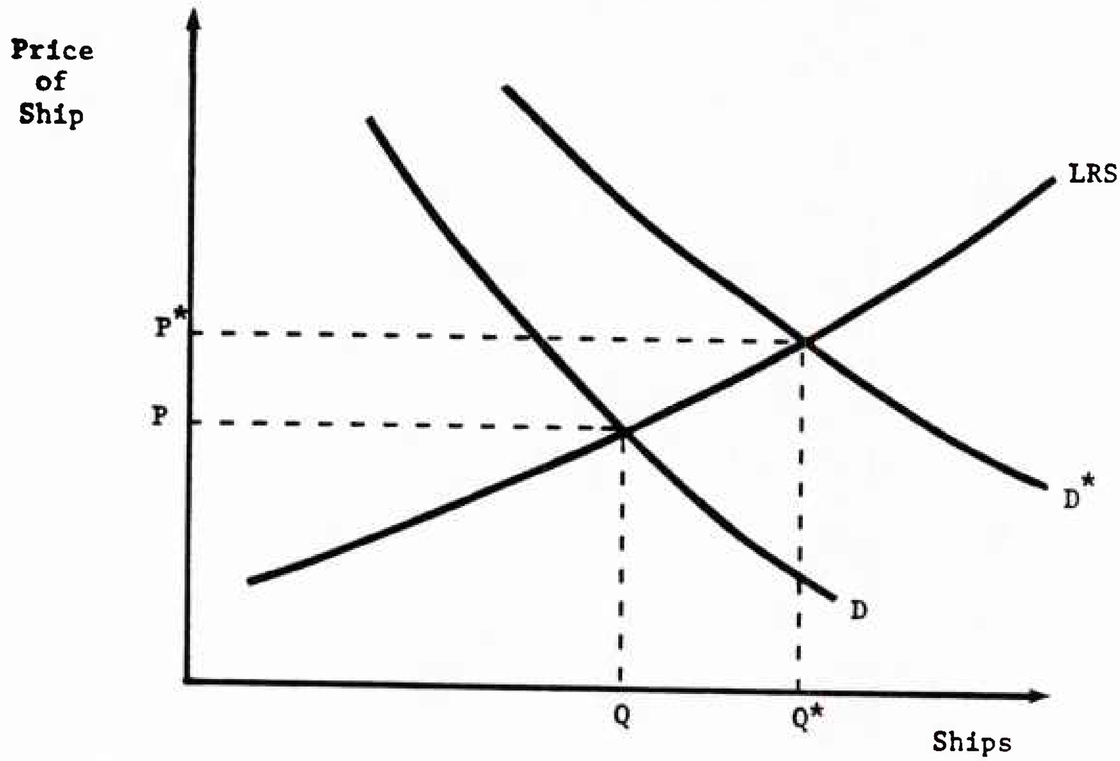


Figure 2.3-2 Shipbuilding Assuming An Upward Sloping Supply

LRS - Long Run Supply (2 to 3 years for shipbuilding)

Q - Quantity Produced without Subsidy

Q*- Quantity Produced with Subsidy

P - Price without subsidy

P*- Price with subsidy

3. PLANNING TOOL CHARACTERISTICS

This chapter describes the characteristics of the ship acquisition planning tool: modifications have been made which distinguish the present form of the planning tool from its previous versions reported in TR-1337 and TR-1337-2. The yard cost estimation procedure is discussed first, and the estimated effect of each variable in the two principal equations is illustrated. The essential features of the new method for determining yard prices and Navy costs are then presented. Finally, the optimization strategy for ship acquisition is briefly described.

The figures in this chapter illustrating functional relationships are based on preliminary data, information and estimates obtained from interviews with knowledgeable people and other data sources. These relationships need to be updated and refined with additional hard data on naval shipbuilding programs.

3.1 ESTIMATING THE COST OF SHIPS

The basic TASC approach for estimating the cost to a given shipyard of building a ship has not changed from previous reports. That is, for a given ship at a particular yard, one starts with the NAVSEA estimates of the following variables: the manhours to build the ship, the cost of subcontracts, and the cost of materials. On the basis of interviews, TASC concluded that direct costs, comprising labor and overhead costs, are most sensitive to such specific yard characteristics as turnover rates, average experience of supervisory personnel,

and other factors affecting overall yard productivity. Thus, the initial (NAVSEA) manhour estimate is modified using the specific yard values for all factors which affect the total building effort. The labor cost is then found using the adjusted manhour estimate and the average wage at the given yard. Material and subcontract estimates, the effect of inflation, and the effect of learning from earlier experience of building similar ships are then combined with the labor cost to obtain the direct cost to the shipyard. The overhead costs are computed by estimating the overhead rate (which is also dependent on several yard-specific factors), and applying it to the direct costs along with the extraordinary capital costs which may be incurred by a shipyard when building a ship of a certain type for the first time. While this basic approach to cost estimation has not changed, the functional relationship used to adjust the manhour estimate has been modified. All equations pertaining to the cost estimation are provided in Appendix A. We emphasize here the importance of TASC's approach to yard cost estimation: <u>the methodology adopted is a heuristic, empirical one, which lends itself to validation and modification through rigorous data analysis. That is to say, data can be used to accept, reject or modify each of the postulated causal relationships between variables</u>.

The rest of this section contains a discussion of the two principal relationships of the cost estimation module -- the manhour adjustment and the overhead rate estimation. The effect of each variable affecting manhours and the overhead rate is individually described and the estimated functional relationship is shown graphically. All the equations pertaining to yard cost estimation can be found in Appendix A.

3.1.1 Modifying the Manhour Estimate

Continued analysis of the manhour adjustment equation led to a modification of the functional relationship presented in TASC reports TR-1337 and TR-1337-2. The basic finding is that the manhours to build a ship depend

- Directly on:
  - Distribution of workers among shifts
  - Turnover rates
  - Proportion of total direct cost attributable to subcontracts
  - Rate of change of yard employment

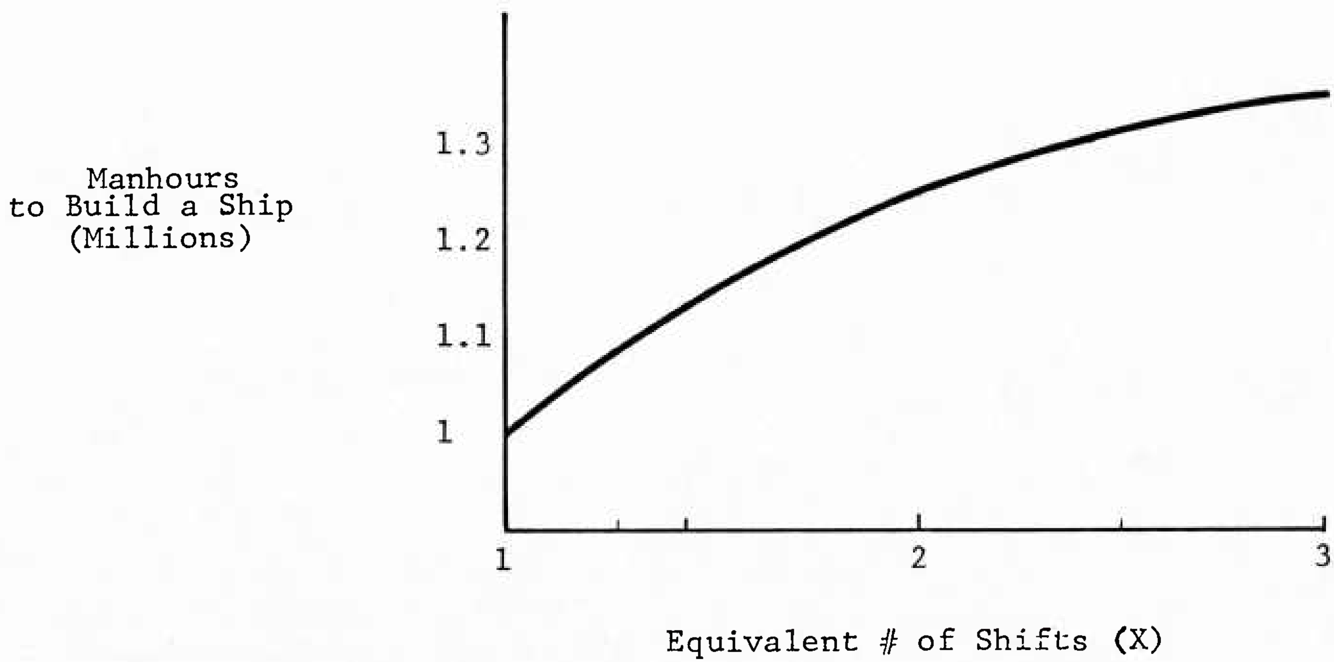
and

- Inversely on:
  - Yard employment-level efficiency factor ("labor window")
  - Average experience of first-level supervisory personnel
  - Average time since hire of work force.

All variables pertain to conditions in the yard under consideration during the particular procurement period. Besides the changes in the functional form of the manhour estimate equation, two of the variables in the equation are now defined differently: turnover rate and the rate of change of employment. Additionally, a new variable -- the distribution of workers among shifts -- has been substituted for the number of shifts, a variable in the manhour estimate equation as presented in TASC reports TR-1337 and TR-1337-2. In the following discussion, the effect of each variable on the manhour

estimate is illustrated on the basis of assuming that, for the nominal value of each influencing variable, it takes one million manhours to build a ship. The degree of influence of each variable can be seen directly by noting the change in the manhours corresponding to unit change in the influencing variable. It should be again noted that the numerical values used represent estimates of conditions in a typical shipyard derived from TASC's analysis of available data and interviews with key naval and shipbuilder personnel responsible for the Navy's shipbuilding program.

Effect of Worker Distribution Among Shifts - Figure 3.1-1 represents the effect on manhours of worker distribution among shifts, or shift loading. Typically, the productivity of workers in shift 1 is higher than the productivity of workers in shifts 2 and 3. In turn, the workers in shift 2 tend to be more efficient than workers in shift 3. Thus, an equal distribution of workers in all three shifts would be the least efficient, if one also assumes that neither shift 2 or 3 will ever have more workers than shift 1. The most efficient distribution of workers -- that is, all workers in the most productive shift 1 -- is clearly not realistic, since in practice there will always be workers in shifts 2 and 3. Also, the variable used to represent worker distribution among shifts is an approximation, since it does not distinguish workers in shift 2 from those in shift 3. The graph in Figure 3.1-1 represents the effect of worker distribution assuming an average or typical distribution of workers in shifts 2 and 3. Thus, a shift loading of 60 per cent of the workers in shift 1 and 40 per cent in shifts 2 and 3 would imply an effort of 1.17 million manhours to build a ship, while a shift loading of 70 per cent in shift 1 and 30 per cent in shifts 2 and 3 would indicate 1.12 million manhours to build the same ship.



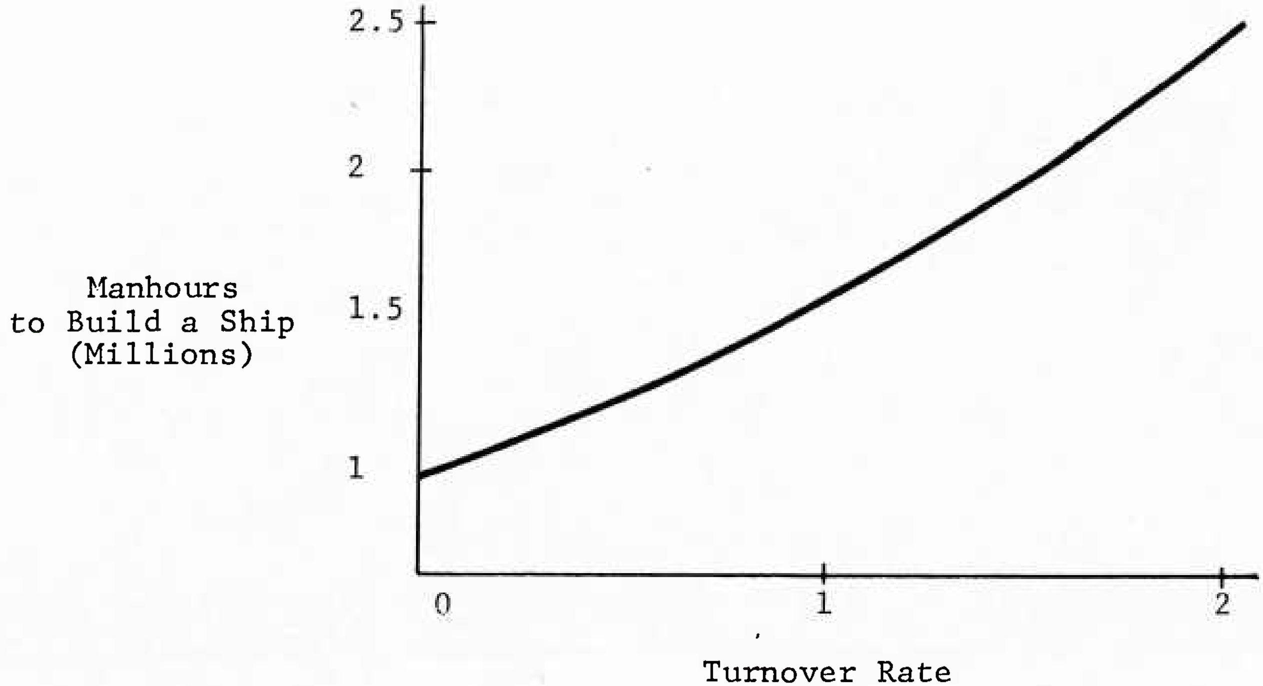
$$\text{Equivalent \# of Shifts} = 1 + \frac{\text{Total \# in Shifts 2 \& 3}}{\text{Total \# in Shift 1}}$$

Figure 3.1-1 Effect of Distribution of Workers Among Shifts on Manhours

Effect of Turnover Rate - Figure 3.1-2 illustrates the effect on manhours of the turnover rate at a shipyard. There are several phenomena associated with turnover of personnel at a shipyard. First, there is the training and familiarization required for newly hired workers; second, workers who leave create voids in the construction process, leading to reassignment of personnel, and training them for their new positions. It is natural to expect the effect of turnover to be more pronounced as turnover rate increases, as shown by the convexity of the manhour graph in Figure 3.1-2. For example, as the turnover rate increases from 0.5 to 1, the manhours required to build a ship increase from 1.25 million to 1.6 million. On the other hand, Figure 3.1-2 shows that as the turnover rate increases from 1 to 1.5, the manhours increase from 1.6 million to 2 million. We should note that a turnover rate of 0.5 is very high, since the typical turnover at actual yards are of the order of 0.2. The numbers used in this example are merely to illustrate the increasing contribution of turnover to yard inefficiency for higher turnover rates.

Effect of Subcontracts - Figure 3.1-3 shows the effect on manhours of the proportion of direct costs attributable to subcontracts. A yard's manhours will decrease as the amount of subcontract work increases, since subcontracts reduce the work to be done at the yard. For example, our preliminary research data displayed in Figure 3.1-3 shows that if subcontracts totalling 25 per cent of the direct costs were used the yard manhours would be reduced by 20 per cent to 800,000 hours.

Effect of Rate of Change of Employment - Figure 3.1-4 depicts the effect on manhours of the rate of change of employment at the yard. If a yard's labor force at year end is different from the labor force at the beginning of the year, the



$$\text{Turnover Rate} = \frac{(\#\ \text{Joining} + \#\ \text{Leaving}) - \left|\#\ \text{Joining} - \#\ \text{Leaving}\right|}{2\ (\text{Average Employment})}\ \text{on an Annual Basis}$$

Figure 3.1-2 Effect of Turnover Rate on Manhours

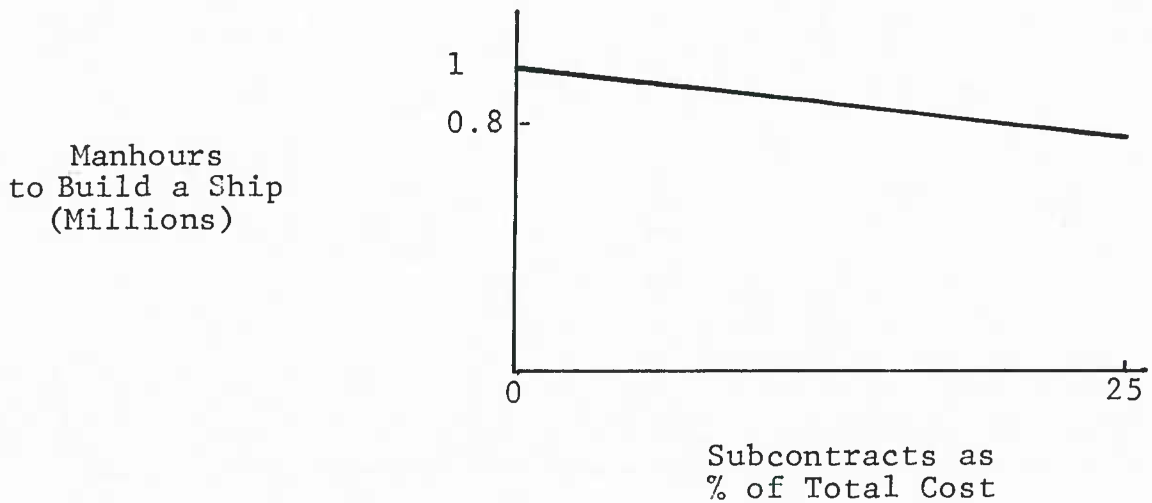


Figure 3.1-3 Effect of Subcontracts on Manhours

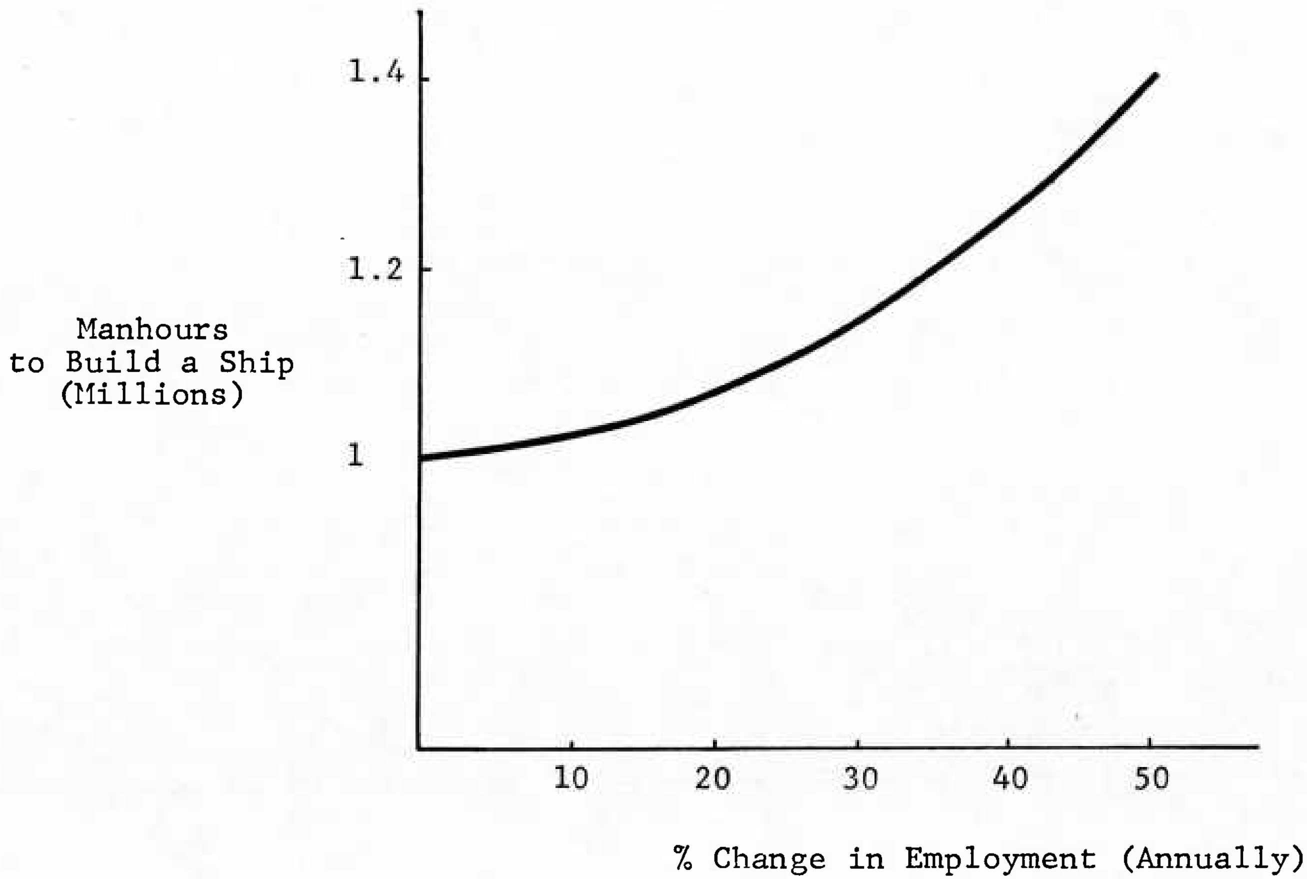


Figure 3.1-4 Effect of Rate of Change of Employment on Manhours

overall ship construction effort will be less efficient than if there had been no change in the yard employment. It should be noted that different temporal variations in yard employment are reflected by the rate of change of employment and the turnover rate. Two extreme examples of work force fluctuations at a yard can be used to illustrate the difference. First, consider a yard where there were fluctuations in the yard employment from month to month, but the labor force at year end was the same as it was at the beginning of the year. These fluctuations would be captured by the turnover rate variable, which has been defined precisely to represent such temporal characteristics of the yard employment. However, the rate of change of employment variable will be zero in this case. Next, consider the same yard with a month to month increase (or decrease) in yard employment. Suppose there were only increases in employment in a certain year. In such a case, the turnover rate would be zero, and the effect of the yard employment level variations would be represented by the rate of change of employment variable. As with all of the postulated relations, the above assertions can be validated or improved by testing with historical data.

Effect of Labor Window - Figure 3.1-5 shows the effect on manhours of the labor window", or the yard-employment level efficiency factor. The "labor window" concept has been discussed extensively in TR-1337 and TR-1337-2. Essentially, each yard is most efficient at a certain employment level, and departures in the yard labor force from this optimal level, whether above or below, reduces the overall yard efficiency. The effect of the "labor window" can be quite marked: for example, in Figure 3.1-5, our preliminary research data shows that a 50 per cent change in employment level from the optimum causes a 100 per cent increase in the manhours to build a ship.

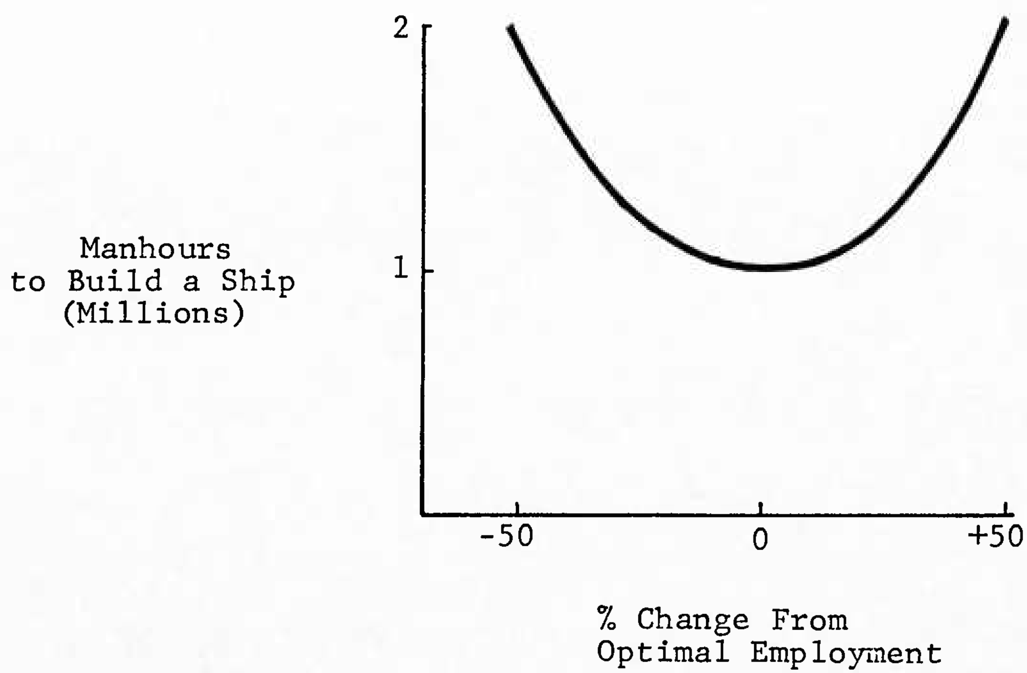


Figure 3.1-5 Effect of Labor Window on Manhours

Effect of Average Experience of First-Level Supervisors - Figure 3.1-6 illustrates the effect on manhours to build a ship of the average experience of first-level supervisors. Efficiency of ship construction increases with greater experience of the entire work force at the yard; however, it was the consensus of interviews conducted by TASC that the efficiency of the building effort was most sensitive to the experience of first-level supervisors. In the example shown in Figure 3.1-6, an increase in the average experience of the supervisors from 5 to 10 years reduces the manhours to build a ship by 19 per cent (from 1 million to 810,000).

Effect of Average Time Since Hire of Work Force - Figure 3.1-7 depicts the effect on manhours to build a ship of the average time since hire of the work force to the mid-point of ship construction. There are always inefficiencies associated with learning and training of personnel, so that higher productivity can be obtained from a work force which has been "on the job" longer. The example illustrated in Figure 3.1-7 shows that a work force that had been on the job an average of 24 months would reduce by about 46,000 (approximately 5 per cent) the manhours required by a work force that had been at the yard an average of 21 months.

3.1.2 Computing The Overhead Rate

The functional form of the overhead rate equation has not been changed from TR-1337 and TR-1337-2; however, as in the manhour equation, the number of shifts has been replaced by the variable representing distribution of workers among shifts. The overhead rate at a yard depends on the following variables:

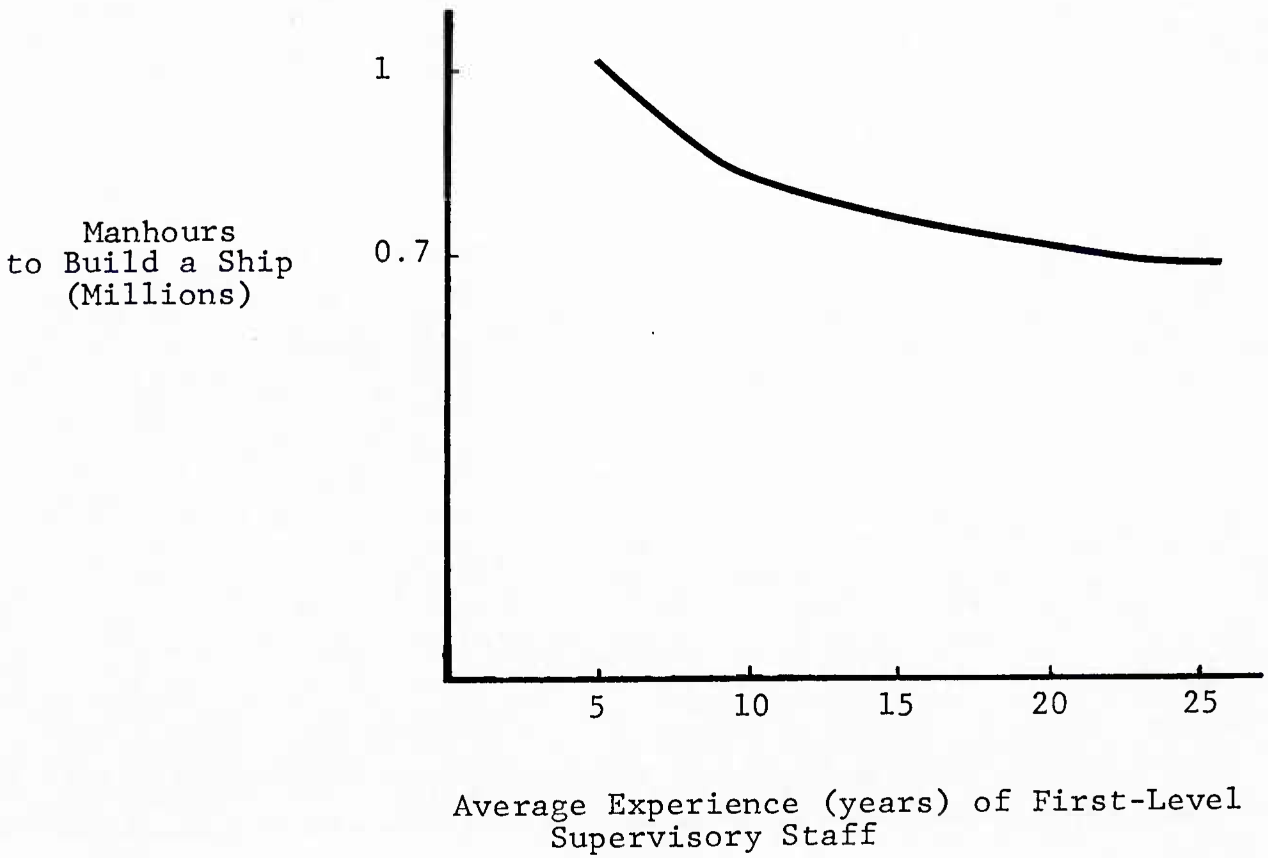


Figure 3.1-6   Effect of Experience on Manhours

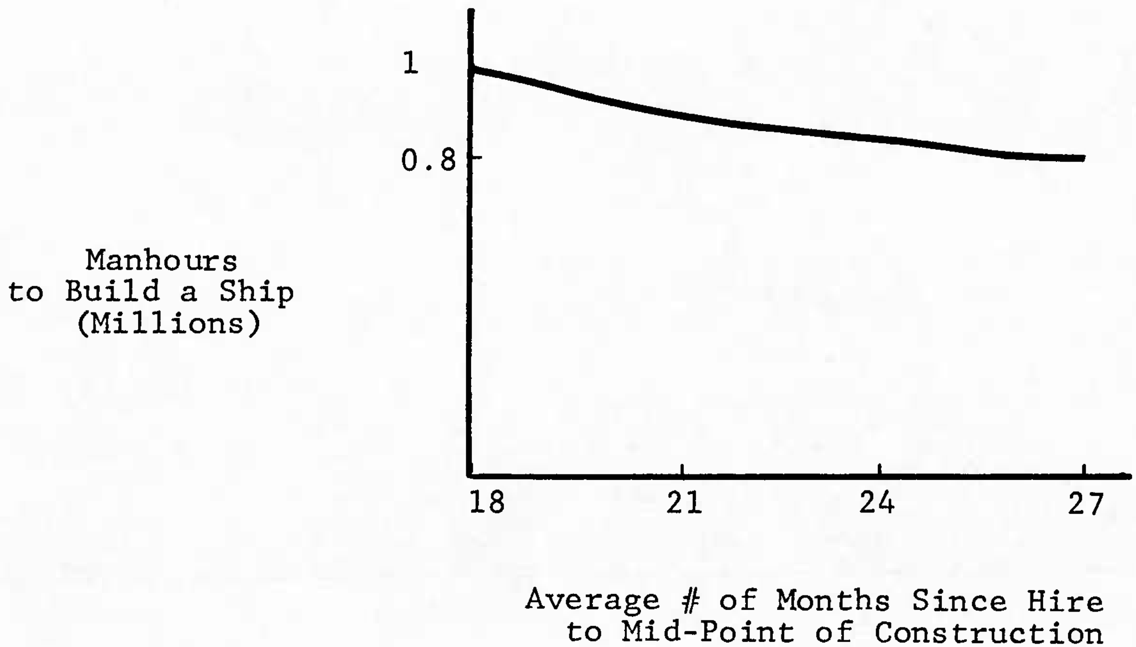
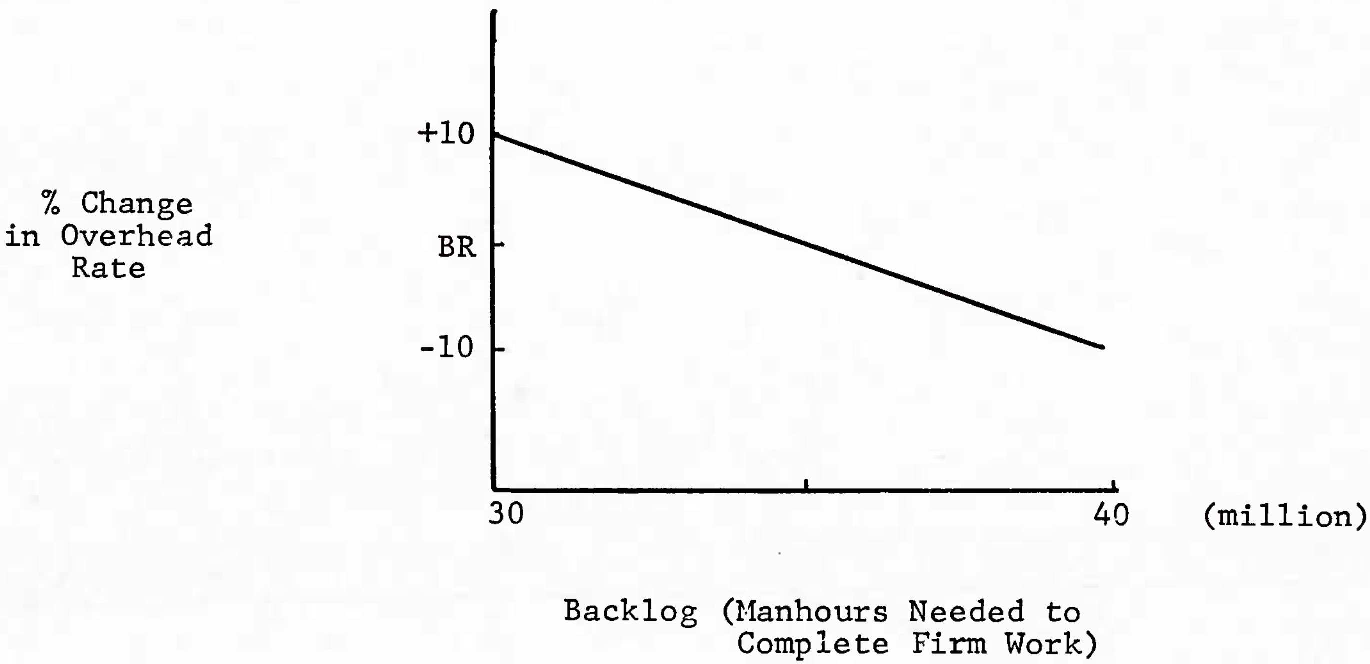


Figure 3.1-7 Effect of Average Time Since Hire on Manhours

- Backlog of work
- Proportion of total direct cost attributable to subcontracts
- Proportion of total direct cost attributable to materials
- Distribution of workers among shifts.

For any yard, there is a base overhead rate which is a function of base values of these variables and such fixed quantities as physical plant equipment and building ways. The variables in the overhead rate equation modify this basic rate. Thus, in the following discussion, the effect of each variable is measured as a percent change in the base overhead rate caused by unit changes of the influencing variable, assuming that all other influencing variables remain constant at their respective baseline values associated with base overhead rate.

Effect of Backlog - Figure 3.1-8 shows the effect of backlog on the overhead rate. In this report, backlog is measured in terms of manhours of effort required to complete work on order at the yard. Such a measure implies that if all work on order at a yard is to be completed in a certain number of months, the average monthly employment required to complete work can be computed directly. Thus, a yard's base overhead rate, which corresponds to a certain backlog of work at the yard, is also associated with an average monthly employment computed in the manner just described. If the backlog falls below this base level, the associated average monthly employment also decreases, so that overhead costs are now spread over a smaller employment base, causing an increase in the overhead rate. Conversely, an increase in the backlog implies an increase in the associated average monthly employment, which



BR: Base Overhead Rate

Figure 3.1-8 Effect of Backlog on Overhead Rate

connotes a lower overhead rate since overhead costs are distributed over a larger employment base. For the example shown in Figure 3.1-8, an increase in the backlog of 17 per cent (from 35 million to 40 million manhours) reduces the base overhead rate by 10 per cent.

Effect of Material Costs - Figure 3.1-9 shows the effect of material costs on the yard overhead rate. The base overhead rate is computed on the assumption that material costs constitute a certain proportion of total direct cost. For instance, it is assumed in the example of Figure 3.1-9 that the base overhead rate corresponds to material costs being 20 per cent of total cost. As the proportion of material cost increases, the overhead rate increases because of greater storage requirements, increased handling, and higher administrative costs. The example shows a 10 per cent increase in the base overhead rate for a material cost increase from 20 per cent to 40 per cent of total cost. For this example only, the overhead rate would decrease if material costs fell below the baseline value of 20 per cent of the total cost.

Effect of Subcontracts - Figure 3.1-10 demonstrates the effect of subcontracts on the overhead rate. In this example, the base overhead rate is computed assuming there are no subcontracts; that is, all work will be done at the yard under consideration. Any work which is let out to subcontractors increases the administrative burden at the yard, which in turn raises the overhead costs and hence the overhead rate. Thus, in Figure 3.1-10, if 25 per cent of the total direct cost is attributable to subcontracts, the base overhead rate increases by 10 per cent.

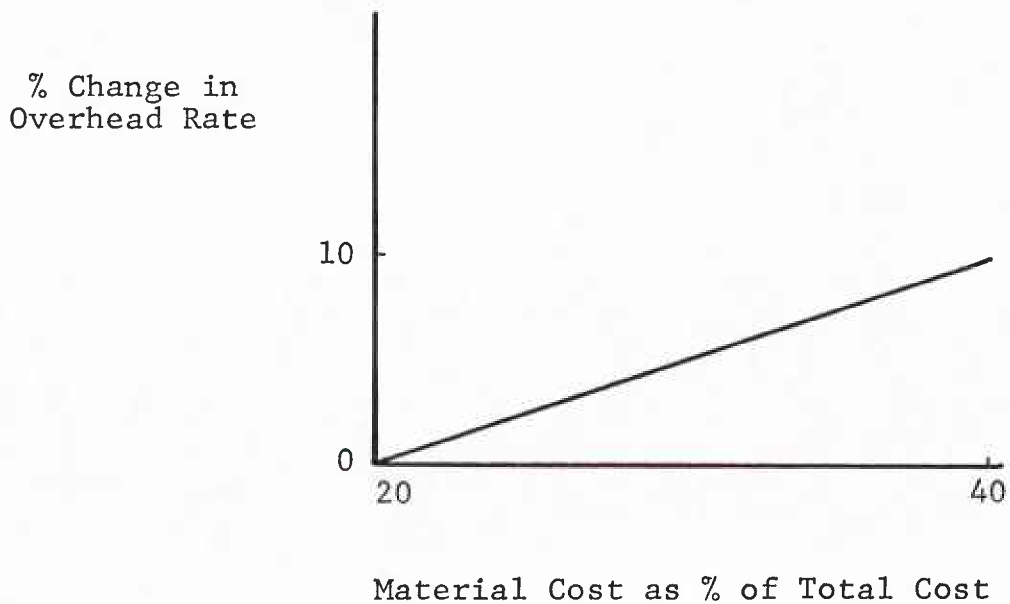


Figure 3.1-9 Effect of Material Cost on Overhead Rate

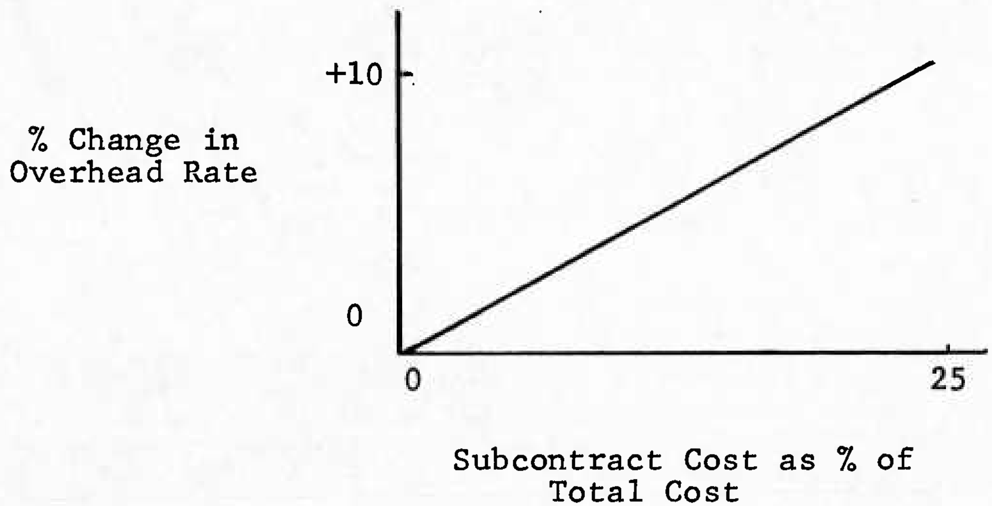


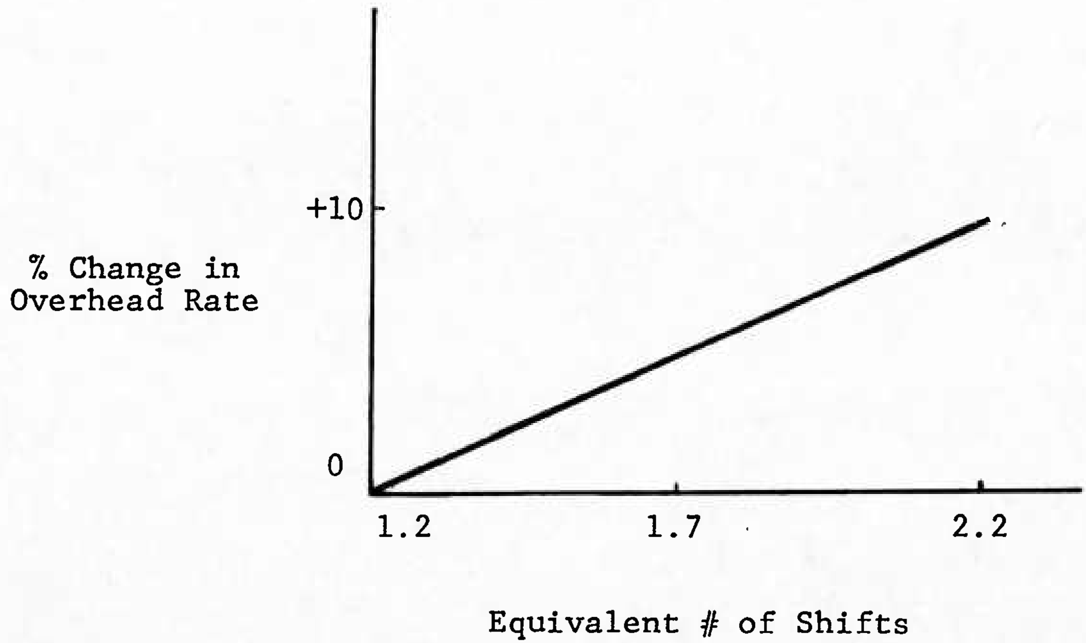
Figure 3.1-10 Effect of Subcontracts on Overhead Rate

Effect of Worker Distribution Among Shifts - Figure 3.1-11 illustrates the effect of worker distribution among shifts on the overhead rate. The base overhead rate takes into account a baseline shift loading: in the example shown in Figure 3.1-11, this baseline loading corresponds to an equivalent shift number of 1.2, which implies a distribution with 83 per cent of the workers in shift 1 and the remaining 17 per cent in shifts 2 and 3. An increase in the equivalent number of shifts means a relative increase in the proportion of shift 2 and 3 workers, which in turn means that higher plant support costs are incurred for these shifts and the overhead rate increases. Thus, a change in shift loading from 83 per cent of workers in shift 1 (equivalent shift number = 1.2) to 59 per cent of workers in shift 1 (equivalent shift number = 1.7) increases the base overhead rate by 5 per cent.

3.2 ESTIMATING YARD PRICES AND THE COST TO THE NAVY OF A GIVEN ALLOCATION.

There has been a significant change in the approach adopted by TASC in determining the cost to the Navy of a given allocation. A fundamental requirement of TASC's previous approach was to estimate, for each yard, the Navy's demand for ships of a given type. As discussed in Chapter 2 of this report, this posed serious technical problems. The new approach is to estimate the Navy's cost for a given allocation using an auction market model.

For any assumed allocation of ships to yards in a procurement period, the individual yard bids are determined first. A relevant set of information could be used to determine a shipyard's bid for a particular ship: this is the most important feature of TASC's new approach to determining yard



$$\text{Equivalent \# of Shifts} = 1 + \frac{\text{Total \# in Shifts 2 \& 3}}{\text{Total \# in Shift 1}}$$

Figure 3.1-11 Effect of Distribution of Workers Among Shifts

prices and the costs to the Navy, since it provides a framework for taking into account commercial shipbuilding activity insofar as commercial shipbuilding affects the cost of the naval shipbuilding program. That is to say, a yard's bid for a particular Navy ship may be determined, in part, by the level of commercial shipbuilding activity at that yard. However, the specific relationships that may actually exist in shipyards between their bids (for Navy ships) and commercial work on hand can only be determined through extensive empirical analysis which would require significant resources beyond the scope of this study. What should be noted is that a methodological framework has now been established to directly take into account commercial shipbuilding at the level of the firm (shipyard). Presently, commercial shipbuilding is incorporated indirectly in the planning tool: first, it is entered as part of the backlog at a yard building Navy ships; second, the level of commercial shipbuilding at a yard limits the yard's capacity for naval shipbuilding, and this capacity constraint affects the program cost optimization described in Section 3.3.

The auction market model requires just the yard bids in conjunction with the bidding environment described by combinations of the following variables:

- Sole source or multiple procurement
- Competitive or non-competitive ("allocated") procurement
- If competitive, whether or not any yard buys in. (This is an input specified by the user on the basis of bidding histories of the different yards.)

The principal features of the auction market in TASC's present form of the planning tool are:

(1) Each shipyard determines its minimum acceptable price on the basis of its objective (e.g. maximize cash flow or return on investment) and its average cost to build a ship of the type under consideration. If a yard has an objective of maximizing cash flow, we believe its minimum price will be to just cover yard costs. On the other hand, if a yard wishes to maximize return on investment, its minimum price will be its average yard cost plus a minimum percentage of costs. During the bidding process, such a yard (i.e., one maximizing return on investment) would try to obtain as much higher a price than its minimum as it possibly can.

(2) For sole source or non-competitive procurement, the price charged to the Navy is negotiated at an increment above the minimum acceptable price.

(3) For a competitive procurement with no yards buying in, the shipyard with lowest minimum acceptable price bids slightly less than the next lowest price. The other shipyards allocated ships in this procurement negotiate their prices with the Navy at increments above their minimum acceptable prices.

(4) If a buy-in occurs, the buy-in bid is based on the lowest yard cost of qualified yards. If the buy-in bid is lower than all other minimum acceptable prices, the price charged to the Navy is computed as in the competitive procurement (Feature 3). If the buy-in bid is not the lowest bid, then the yard buying in negotiates a price with the Navy, while the other yards charge prices as computed in the competitive procurement with no buy-ins (Feature 3).

3.3 OPTIMIZING SHIP ACQUISITION STRATEGY

The optimization algorithm described and discussed in Section 2.9 of TR-1337-2 was implemented in the ship acquisition planning tool. That is, a combination of extended Lagrange multiplier and centroid techniques was used to find the lowest cost procurement for the Navy under given constraints. Noting that a different approach was adopted for price estimation and determination of Navy costs, the following function was the expression to be minimized:

$$\text{Modified Total Cost} = \underline{P} \cdot \underline{q} + \Sigma\, \lambda_i \text{ (i-th constraint function)}$$

where $\underline{P}$ = the vector of prices paid by the Navy

$\underline{q}$ = the vector of numbers of ships of each type produced by each yard

λ_i = Lagrange multipliers, whose initial values are artibitrarily chosen

Figure 3.3-1 is a flow chart diagramming the essential steps in the optimization algorithm. As mentioned in Section 2.9 of TR-1337-2, the evaluation of the constraints determined whether or not a λ value was to be increased or decreased. In summary, the principal features of the optimization algorithm are:

- Finds total acquisition strategy which yields least cost in presence of constraints: adjustments may increase cost of a particular program (i.e., a particular ship type) to achieve greater cost decrease in others.
- Can consider different constraints, e.g. limits of yard capabilities and capacities. Some minimum building programs may be stipulated for certain yards.
- Allows detailed examination of alternative allocations.

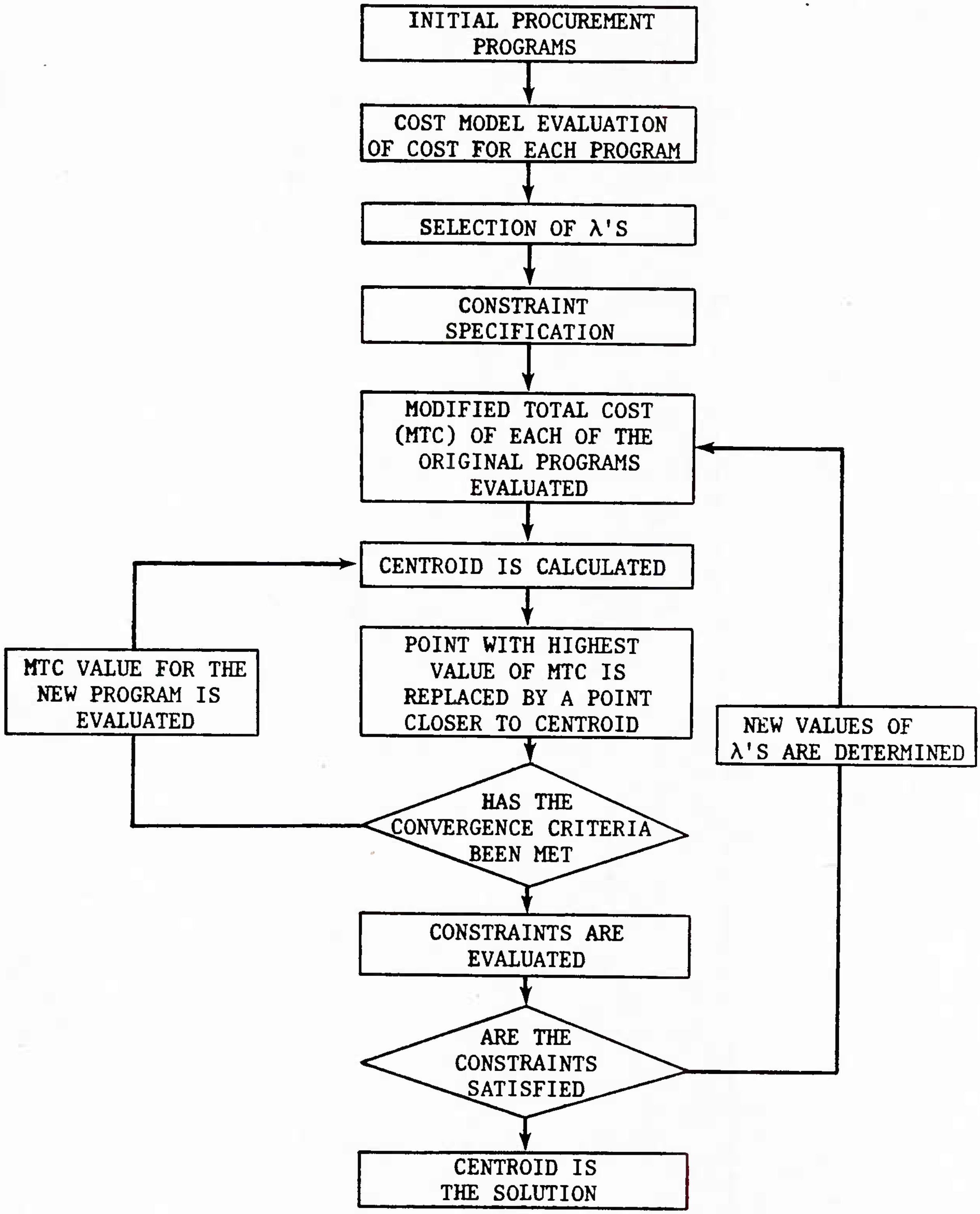


Figure D-1 Flow Chart of the Optimization Algorithm

4. DATA COLLECTION AND IMPLEMENTATION IN ACQUISITION PLANNING TOOL

This chapter describes the results of our data collection efforts with regard to both naval and commercial shipbuilding. While all sources of data were identified, most data were not available during the performance of this work. The two primary reasons for data not being fully developed during the period of performance of this work were: (1) The Navy sources felt that their gathering the amount of needed data would be difficult, and hence expensive; and (2) the scope of the contract did not provide for TASC to develop the data from other sources, even if available. Thus, the data acquired were insufficient for fully testing, validating and modifying the planning tool. However, the acquired data along with interviews and other sources were used to form estimates of parameters required to develop and exercise the planning tool to the point of confidence in its basic ability to perform as a ship acquisition planning tool.

4.1 DATA COLLECTION

4.1.1 Naval Shipbuilding

Table 4.1-1 lists the data needed for validating, improving and exercising the ship acquisition planning tool. We note that the ship-specific bid data need to be known for each yard that bid for the ship.

TABLE 4.1-1
DATA REQUIREMENTS

SHIP-SPECIFIC DATA	SHIPYARD DATA
Contract Awards	Total Employment (Annual)
Contract Start Date	Production Employment (Annual)
Delivery Date	Backlog
Budget Estimate	Experience of Workers
Bids (By Yard)	Labor Turnover Rate (Annual)
Actual Cost of Vessel	Manpower Loading
Manhours to Build	
Total Material Cost	
Total Subcontract Cost	
GFE Cost	
Overhead Rate	
*Exceptional Fixed Cost	

* This item refers to any fixed investment which must be made in a yard which is building a ship of a certain type for the first time.

Table 4.1-2 lists the different Navy sources of data identified by TASC and the data that could be provided by these sources.

TABLE 4.1-2
SOURCES OF DATA

SOURCE	DATA
Ship Acquisition Program Managers (SHAPMs)	DOD I 7000.2//DOD I 7000.10 Work Breakdown Structure Cost by Work Breakdown Structure Manpower Loading Schedule Backlog Yard bids
NAVSEA 01	Schedule Yard Employment Production Employment Backlog
NAVSEA 07	Return Costs Shipbuilding Contracts GFE

It should be noted that the data which is reported to the SHAPMs contain the information needed to obtain labor turnover rates and worker experience at yards.

Finally, Table 4.1-3 shows the naval data which we were able to obtain.

TABLE 4.1-3
NAVAL DATA OBTAINED

SOURCE	DATA
NAVWESA	FFG 7 class data, modified
NAVSEA 90	- Complete data set for FFG 8 built at Bath Iron Works
	- Shipyard order books and workload projections (Dec 1978 - March 1981)
	- Navy ships built or converted between 1960 - 1980 with their beginning and end of construction times
	- Partial data for one each of AO 177, AD41 and AS39 built at AVONDALE, NASSCO and LOCKHEED shipyards

4.1.2 Commercial Shipbuilding

Most of the data on commercial shipbuilding came from the Maritime Administration (MARAD). Specifically, for each ship, this included contract award date, start of fabrication, type of ship and tonnage, shipyard where ship was built, cost, and if subsidized, amount of subsidy. These data were available from 1972 to 1981. Additional information on ships built, such as name and vessel owner, were also available.

Details on ship construction subsidies were provided by MARAD, from the Office of Shipbuilding Costs. This office

also provided some information on the costs of shipbuilding in foreign shipyards which compete with US shipyards for orders for ships to be used in US foreign trade. Many other sources, such as the OECD, provided data on comparable US and foreign ship construction (e.g. tonnage produced per annum, types of ships constructed, total value of ship construction, total exports and imports to that country, use of foreign flag vessels etc.).

Some shipyard-specific data were also collected. This shipbuilding industrial base, as agreed between the Navy and the Maritime Administration, consists of 26 shipyards which define themselves as actively looking for shipbuilding work. In practice these yards may be divided into four categories: (1) those which do Navy ship construction exclusively, (2) those which do commercial construction exclusively, (3) those which do both Navy and commercial construction, and (4) those who are temporarily inactive in construction but active in ship conversion and repair. (See Table 4.1-4 for a breakdown of the shipbuilding base into categories.)

Shipyard specific data which were available on a non-proprietary basis were generally aggregated. However, some data on specific shipyards (full-time production employment, labor turnover, and backlog) were obtained from NAVSEA 90. However, this data were limited in its scope as the time period included only December 1978 to March 1981.

In terms of the size of ships included in the commercial side of ship acquisition, only ships of 1,000 g.r.t or more were considered, thereby excluding many commercial vessels such as fishing craft, tugs and barges for inland waterways or coastal use. Most of the production workers employed in commercial shipbuilding work on the larger ship contracts

TABLE 4.1-4

ACTIVE SHIPBUILDING BASE

Shipyard	Exclusively Navy Construction	Exclusively Commercial Construction	Navy or Commercial Construction	Conversion or Repair
Alabama				X
American Lorain		X		
Avondale			X	
Bath			X	
Bay		X		
Bethlehem Steel, San Francisco				X
Bethlehem Steel, Sparrows Point		X		
Equitable		X		
Gen. Dynamics, Groton	X			
Gen. Dynamics, Quincy		X		
Levingston		X		
Litton (Ingalls)	X			
Lockheed	X			
Marinette Marines				X
Maryland				X
NASSCO			X	
Newport News			X	
Norfolk				X
Peterson				X
Pennsylvania**		X		
Tacoma		X		X
Tampa*				X
Todd, Galveston		X		
Todd, Houston		X		
Todd, Los Angeles	X			X
Todd, Seattle			X	

* Also builds off-shore platforms
** Formerly Sunship, now a subsidiary of Levingston

and these contracts have the greater impact on any competition that may occur with the Navy for use of a certain shipyard's resources.

4.2 IMPLEMENTATION OF DATA IN THE ACQUISITION PLANNING TOOL

The most significant problem of this project was the non-availability of data. As mentioned in Chapter 3, the basis of TASC's approach to yard cost and price estimation is that all postulated relationships can be tested by data for validity and, if necessary, appropriately modified. The lack of data prevented the determination of cost sensitivities to the various factors affecting yard costs and prices. It precluded any rigorous testing of the preliminary relationships by standard statistical procedures of linear and non-linear regression analysis. We must emphasize here the importance of further collecting and developing these data for anyone wishing to perform serious analysis of the ship acquisition problem. Acquiring the data listed in Section 4.1 is quite essential to fully defining the important cost drivers in shipbuilding.

The naval shipbuilding data on hand coupled with interviews with knowledgeable people, allowed us to form simplistic estimates of parameter values so that the planning tool could be demonstrated. The commercial shipbuilding data that were collected were insufficient even to form estimates for exercising the planning tool. Most importantly, insufficient Navy and commercial data prevented a systematic examination of either the impact of commercial shipbuilding on bids for Navy ships, or of the effect of commercial shipbuilding subsidies on bids for commercial ships.

5. DEMONSTRATION RESULTS

The results of demonstrating the ship acquisition planning tool for three examples are described in this chapter. The purpose of the demonstration was to prove the operational feasibility of the planning tool. Simple, low dimensional problems were considered. Thus, the numerical values of parameters and variables used in the examples represent estimates of conditions in typical shipyards derived from TASC's analysis of available data and interviews with key naval and shipbuilder personnel responsible for the Navy's shipbuilding programs. All the examples dealt with the problem of finding the allocation with the least cost to the Navy for a three year procurement of seven ships of one type and five of another, with the same two yards qualified to build each type of ship. For each example, ship acquisition by the Navy was assumed to take place in an auction market environment. The auction market for the first two examples was a straightforward one, while the third example's auction featured the added complexities of "buy-in"s by less efficient yards and non-competitive assignment (of ships) to yards by the Navy. Section 5.1 describes the input data used for the demonstration while Section 5.2 provides the results of the demonstration.

5.1 INPUT DATA

The input data which had to be specified fall into four categories:

- Shipyard characteristics for yard cost computation
- Auction characteristics for Navy cost determination
- Constraints affecting the least cost allocation
- Sample allocations.

Each category of input data is described separately in the following paragraphs.

The input data for computation of yard costs for building a particular type of ship were of three types:

(i) Parameters of the different cost equations. These parameter values remained constant for each yard during all procurement periods under consideration.

(ii) Yard-specific and ship-type-specific variables whose values changed from one procurement period to another. These values were all specified as inputs.

(iii) Other yard-specific and ship-type-specific variables different from those of type (ii), whose values changed from one procurement period to the next; however, the only values specified as inputs for these variables were the ones representing conditions at the beginning of the initial procurement period. Other values for these variables were computed by the planning tool as intermediate results.

Tables 5.1-1 to 5.1-7 present the input data for the shipyard cost computation. Tables 5.1-1 to 5.1-3 show the principal relations used for yard cost determination. The numerical values in Tables 5.1-1 to 5.1-3 are thus the parameters which

characterize the shipyards. Two other parameters of the shipyards are the optimum yard employment (OM) and the learning curve coefficient (LC), whose constant values appear in Table 5.1-4. It should be noted that in Tables 5.1-1 to 5.1-3, all the variables except H, ΔM, M, L, L_A, B and Y are variables of type (ii), whose values for all procurement periods were specified as inputs. Tables 5.1-4 to 5.1-6 show the values of both types of variables for the initial procurement period. For Examples 1 and 2, the values shown in Tables 5.1-5 and 5.1-6 for the subcontract cost, V, and the material cost, R, were the ones used for the R and V for the next two periods as well. However, for Example 3, different increased values were specified for R and V for each of the next two periods. For all three examples, the values specified in Tables 5.1-5 and 5.1-6 for the initial manhour estimate, H_o, were used for all three procurement periods. Table 5.1-7 lists the annual inflation rates used in the planning tool exercise for labor, materials, subcontracts, and GFE costs.

The next set of inputs to be specified comprised the characteristics of the auction market which would determine the cost to the Navy for a given procurement. Table 5.1-8 lists the auction characteristics used for Examples 1 and 2, while Table 5.1-9 indicates the general auction characteristics for Example 3. Table 5.1-10 provides specific details with regard to the "buy-in" and non-competitive allocations used in Example 3. In determining the Navy's cost of a ship, GFE costs have to be added, and these were specified as well. For Examples 1 and 2, the GFE costs were specified as $10 million and $15 million in each period for ship type 1 and ship type 2, respectively. For Example 3, the GFE costs were specified for the initial period as $25 million and $35 million for ship types 1 and 2 respectively. Increased values of GFE costs for both ship types were specified for each of the following periods to account for inflation.

TABLE 5.1-1

SHIPYARD CHARACTERIZATION: MANHOUR ESTIMATE EQUATION

Yard 1

$$H = \frac{1.036\ H_o(1+0.45T+0.15T^2)\ [\ell n(S+2.51)]\ [1-0.75\ (\frac{V}{L+V+R})]\ [1+(1.7 \times 10^{-7})(\Delta M)^2]}{Y(A-17)^{0.0969}\ (E-4)^{0.117}}$$

Yard 2

$$H = \frac{0.839\ H_o(1+0.4T+0.1\ T^2)\ [\ell n(S+3.18)]\ [1-0.85\ (\frac{V}{L+V+R})]\ [1+(1.1 \times 10^{-7})(\Delta M)^2]}{Y(A-18)^{0.085}\ (E-5)^{0.092}}$$

Where:

- H: Adjusted manhour estimate
- H_o: Initial manhour estimate
- T: Turnover rate
- S: Shift loading
- V: Subcontract cost estimate
- R: Material cost estimate
- L: Labor cost estimate (initial)
- ΔM: Change in yard-employment from previous procurment period
- Y: Labor window
- A: Average time since hire of work force
- E: Average experience of first-level supervision

TABLE 5.1-2
SHIPYARD CHARACTERIZATION: LABOR WINDOW

Yard 1

$$Y = 1.8 \times 10^{-8} \; (M-OM)^2$$

Yard 2

$$Y = 1.2 \times 10^{-8} \; (M-OM)^2$$

Where

- M: Yard employment
- OM: Optimum yard employment
- Y: Labor window

TABLE 5.1-3
SHIPYARD CHARACTERIZATION: OVERHEAD RATE EQUATION

Yard 1

$$O_R = 0.4 - (2.3 \times 10^{-9})\; B + 0.13 \left(\frac{R}{L_A+V+R}\right) + 0.5 \left(\frac{V}{L_A+V+R}\right) + 0.03\; S$$

Yard 2

$$O_R = 0.3 - (3.2 \times 10^{-9})\; B + 0.11 \left(\frac{R}{L_A+V+R}\right) + 0.6 \left(\frac{V}{L_A+V+R}\right) + 0.02\; S$$

Where:

- O_R: Overhead rate
- B: Backlog
- R: Material cost estimate
- V: Subcontract cost estimate
- L_A: Adjusted labor cost = H·W, where W is the average wage rate at the yard, and H is the adjusted manhour estimate
- S: Shift loading

TABLE 5.1-4

VALUES OF YARD-SPECIFIC VARIABLES AND PARAMETERS

(Common to both ship types)

Variable	Symbol	Yard 1	Yard 2
Turnover rate	T	0.12	0.14
Shift loading (Equivalent number of shifts)	S	1.3	1.7
Average wage rate ($/hour)	W	7	7.5
Backlog (hours)	B	30×10^6	20×10^6
Yard employment	M	4500	3000
Optimum yard employment	OM	4000	3500
Learning curve coefficient (%)	LC	4	6

NOTES

1. Values shown for T, and S were for initial period only; different values were specified for the other two periods.

2. Values shown for B and M were for the beginning of the initial period; different values of these variables were computed during the planning tool demonstration.

3. Values shown for OM and LC remained constant, as these are yard parameters.

4. Values for W were for all three periods in Examples 1 and 2, while they were used only for the initial period in Example 3; different values were specified for the other two periods in Example 3.

TABLE 5.1-5

INITIAL VARIABLE VALUES FOR SHIP TYPE 1

Variable	Symbol	Yard 1	Yard 2
Initial manhour estimate	H_o	38×10^6	38×10^6
Subcontract cost estimate ($)	V	10×10^6	10×10^6
Material cost estimate ($)	R	35×10^6	35×10^6
Labor cost estimate ($)	L	26.6×10^6	28.5×10^6
Average experience of first level supervision (years)	E	7	6.5
Average time since hire of work force (months)	A	21	21

NOTES:

1. Value shown for H_o was used for each period.
2. Values shown for V and R were used for each period in Examples 1 and 2. Different values for V and R were specified for each of the two following periods in Example 3.
3. Values shown for L were for the beginning of initial period; different values of L were computed during the planning tool demonstration.
4. Values shown for E and A were for initial period only; different values were specified for each of the following two periods.

TABLE 5.1-6

INITIAL VARIABLE VALUES FOR SHIP TYPE 2

Variable	Symbol	Yard 1	Yard 2
Initial manhour estimate	H_o	70×10^6	70×10^6
Subcontract cost estimate ($)	V	15×10^6	15×10^6
Material cost estimate ($)	R	60×10^6	60×10^6
Labor cost estimate ($)	L	49×10^6	52.5×10^6
Average experience of first level supervision (years)	E	8	8.5
Average time since hire of work force (months)	A	19	23

NOTES:

1. Value shown for H_o was used for each period.
2. Values shown for V and R were used for each period in Examples 1 and 2. Different values for V and R were specified for each of the two following periods in Example 3.
3. Values shown for L were for the beginning of initial period; different values of L were computed during the planning tool demonstration.
4. Values shown for E and A were for initial period only; different values were specified for each of the following two periods.

TABLE 5.1-7

ANNUAL INFLATION RATES

Variable	Inflation rate (%)
Labor cost	10
Material cost	9
Subcontract cost	8
GFE cost	8

TABLE 5.1.8

AUCTION CHARACTERISTICS FOR EXAMPLES 1 AND 2

- EACH SHIPYARD CHOOSES ITS MINIMUM ACCEPTABLE PRICE
  - BASED ON YARD OBJECTIVE FUNCTION
- YARD 1 OBJECTIVE: MAXIMIZE RETURN ON INVESTMENT
- YARD 2 OBJECTIVE: MAXIMIZE CASH FLOW
- SHIPYARD WITH LOWEST MINIMUM ACCEPTABLE PRICE BIDS SLIGHTLY LESS THAN NEXT LOWEST PRICE
  - CAN HAVE AS MANY AS ALLOWED
- IF OTHER SHIPYARDS ARE ALLOCATED SHIPS, PRICE NEGOTIATED AT INCREMENT ABOVE COST

TABLE 5.1-9

GENERAL AUCTION CHARACTERISTICS FOR EXAMPLE 3

- EACH SHIPYARD CHOOSES ITS MINIMUM ACCEPTABLE PRICE
  - BASED ON YARD OBJECTIVE FUNCTION
- YARD 1 & 2 HAVE SAME OBJECTIVE:
  MAXIMIZE RETURN ON INVESTMENT
- SHIPYARD WITH LOWEST MINIMUM ACCEPTABLE PRICE BIDS SLIGHTLY LESS THAN NEXT LOWEST PRICE
  - CAN HAVE AS MANY AS ALLOWED
- IF OTHER SHIPYARDS ARE ALLOCATED SHIPS, PRICE NEGOTIATED AT INCREMENT ABOVE COST
- BUY-INS CAN OCCUR
  - WINNER CHOSEN ON BASIS OF BID, NOT GROWTH PRICE
- SHIPS CAN BE ASSIGNED BY NAVY TO SHIPYARDS WITHOUT COMPETITION

TABLE 5.1-10

SPECIFIC AUCTION CHARACTERISTICS FOR EXAMPLE 3

- BUY-IN BY YARD 1 ON SHIP TYPE 1 IN YEAR 3
- NON-COMPETITIVE ALLOCATION FOR SHIP TYPE 1 IN YEAR 2
- NON-COMPETITIVE ALLOCATION FOR SHIP TYPE 2 IN YEAR 3

The next inputs constitute constraints imposed upon the least cost allocation. These constraints were of the following kinds:

- Program size by ship type. In other words, the number of ships of each type required by the Navy was fixed.

- Yard capacities. Each yard had a certain capacity for building a particular type of ship, and it was also limited in the total number of ships it could build of all types.

- Minimum yard programs -total buy. Each yard had to have a certain number of ships to build over all three procurement periods.

- Minimum yard programs - annual. Each yard had to get at least one ship each year. This constraint was in effect only in Examples 2 and 3.

Table 5.1-11 provides the specific details of the constraints used in the planning tool demonstration.

TABLE 5.1-11

CONSTRAINTS

- PROGRAM SIZE - BY SHIP TYPE
  - TOTAL NUMBER OF SHIP TYPE 1 = 7
  - TOTAL NUMBER OF SHIP TYPE 2 = 5

- YARD CAPACITY - BY SHIP TYPE AND BY TOTAL PROGRAM
  - YARD 1 CAN BUILD AT MOST 2 SHIPS OF EITHER TYPE, AND 3 SHIPS IN TOTAL IN ANY PROCUREMENT PERIOD
  - YARD 2 CAN BUILD AT MOST 2 SHIPS OF TYPE 1, 3 SHIPS OF TYPE 2 AND 4 SHIPS IN TOTAL IN ANY PROCUREMENT PERIOD

- MINIMUM YARD PROGRAMS - TOTAL BUY
  - YARD 1 MUST GET AT LEAST 4 SHIPS
  - YARD 2 MUST GET AT LEAST 5 SHIPS

- MINIMUM YARD PROGRAMS - ANNUAL (FOR EXAMPLES 2 & 3 ONLY)
  - EACH YARD MUST GET AT LEAST ONE SHIP EACH YEAR

The final inputs provided for the planning tool exercise were sample allocations of the twelve ships to the two yards, by ship type for each of the three years. All the sample allocations were made so as not to violate any of the constraints indicated in Table 5.1-11. Three of the sample allocations are shown in Table 5.1-12.

TABLE 5.1-12
SAMPLE ALLOCATIONS

	SHIP TYPE 1		SHIP TYPE 2	
	YARD 1	YARD 2	YARD 1	YARD 2
Allocation 1				
YEAR 1	1	1	1	2
YEAR 2	1	1	1	1
YEAR 3	1	0	1	1
Allocation 2				
YEAR 1	1	1	1	2
YEAR 2	2	0	1	1
YEAR 3	1	0	1	1
Allocation 3				
YEAR 1	0	2	1	1
YEAR 2	1	0	0	2
YEAR 3	1	1	1	2

5.2 OUTPUTS AND DISCUSSION

The planning tool was demonstrated for each of the three examples described in Section 5.1. The least cost program found for Example 1 is shown in Table 5.2-1.

TABLE 5.2-1
RESULTS FOR EXAMPLE 1

LOWEST COST PROGRAM				
	SHIP TYPE 1		SHIP TYPE 2	
	YARD 1	YARD 2	YARD 1	YARD 2
YEAR 1	2/$285M	0/ -	0/ -	2/$409M
YEAR 2	1/$145M	1/$126M	1/$247M	2/$424M
YEAR 3	0/ -	1/$121M	0/ -	2/$405M

PROGRAM COST $2,162 MILLION

NOTE

Each entry in the table is of the form A/B, where A is the number of ships of that type allotted to the yard in that year, and B is the total cost to the Navy of these A ships in millions of dollars.

The least cost program for Example 2, which was identical to Example 1 except for the added constraint of each yard having at least one ship awarded each year, is shown in Table 5.2-2.

TABLE 5.2-2
RESULTS FOR EXAMPLE 2

LOWEST COST PROGRAM				
	SHIP TYPE 1		SHIP TYPE 2	
	YARD 1	YARD 2	YARD 1	YARD 2
YEAR 1	2/$285M	0/ -	0/ -	2/$409M
YEAR 2	1/$146M	1/$127M	0/ -	2/$411M
YEAR 3	0/ -	1/$121M	1/$249M	2/$423M

PROGRAM COST $2,171 MILLION

<u>NOTE</u>

Each entry in the table is of the form A/B, where A is the number of ships of that type allotted to the yard in that year, and B is the total cost to the Navy of these A ships in millions of dollars.

An immediate conclusion following from a comparison of the results for Examples 1 and 2 is that the added constraints of each shipyard getting at least one ship each year costs the Navy an additional $9 million, which is not a significant amount compared to the $2.171 billion total price. However, the real significance of this result is that the planning tool can be used to estimate the cost to the Navy of constraints subject to which shipbuilding procurements must be made. In addition, several other explanations need to be made regarding the results shown in Tables 5.2-1 and 5.2-2.

First, the results clearly indicate that it is significantly cheaper for the Navy to build ships at yard 2 than to build them at yard 1. The main reason for this is simple:

although the yard cost for building either ship type does not differ much from yard 1 to yard 2, the Navy's cost is higher for yard 1 because of yard 1's objective of maximizing return on investment; similarly, the Navy's cost for either ship type is lower for yard 2 because yard 2 maximizes cash flow. In other words, when yard costs are comparable, the costs to the Navy are essentially governed by the yards' economic objectives. Next, although it is clearly much cheaper for the Navy to have ships of both types built at yard 2, the procurement program is limited both by yard 2's capacity (by ship type and by total each year) as well as by the constraint of having at least four ships built at yard 1. Also, the objective of the planning tool exercise was the lowest total program cost, and <u>not</u> the cost of individual programs.

It can next be noted that the lowest cost ship procurement programs of Examples 1 and 2 differ only in that one ship of type 2 is awarded to yard 1 in year 3 in Example 1, while it is awarded to yard 1 in year 2 in Example 2. The allocation of ship type 1 for both yards and of ship type 2 to yard 2 is the same in both examples. Yet, the Navy's average cost per ship of type 2 in yard 2 in each of years 2 and 3 in Example 1 is quite different from its corresponding costs in years 2 and 3 in Example 2. This apparent anomaly is caused by the fact that the auction market for examples 1 and 2 treated the event of a single yard being awarded ships like a sole source procurement. This had the effect of lowering the price charged by the more efficient yard, since in competition the more efficient yard would bid closer to the higher price of the less efficient yard. By the converse of the same reasoning, if only the less efficient yard was awarded ships, it would get a greater amount per ship than it would obtain in competition, when the other (more efficient) yard also was awarded some ships.

Finally, given a ship type and a yard, one would expect the cost per ship to increase from one year to the next because of inflation and decrease because of learning (to build ships of the given type). However, in the inputs specified for Examples 1 and 2, the material cost (R) and subcontract cost (V) were the same each year, given a ship type. Also, the wage rate (W) remained the same for each period, given a yard. Thus, the usually more dominant effects of inflation, caused by higher material, subcontract and labor costs for starting ship construction in a later year were absent from Examples 1 and 2. Inflation was taken into account only in terms of the total time to build, and clearly this would be more or less independent of which year the ship construction started, since the estimated time to build a given ship in a certain yard would not change much year to year. Thus, the effect of learning predominated the final Navy costs in Examples 1 and 2. It should be noted that the input set specified for Example 3 was modified from those in Examples 1 and 2, and had the more realistic situation of inflated material and subcontract costs, as well as inflated wage rates, in proceeding from the initial period to the last.

The lowest cost program for Example 3 is shown in Table 5.2-3. The differences between Example 3 and Example 1 and 2 have already been noted, in terms of input data as well as of the auction model used to determine the Navy's cost of a ship procurement. The first observation that should be made is that the optimization module of the planning tool finds the lowest cost program on the basis of bid prices. As shown in Table 5.2-3, that cost would probably escalate by $25 million because of change orders causing growth in the buy-in price of yard 1. This buy-in bid of yard 1 for ship type 1 was based on yard 2's average yard cost and thus was lower than the Navy's cost for ship type 1 built in yard 1 in year 2. Table 5.2-3 also shows that, except for the buy-in bid, all the

other costs per ship in each yard increase because of inflation. Thus, for example, the Navy's cost for each ship of type 2 built at yard 2 increases by 22 per cent from year 1 to year 3.

TABLE 5.2-3

RESULTS FOR EXAMPLE 3

LOWEST COST PROGRAM				
	SHIP TYPE 1		SHIP TYPE 2	
	YARD 1	YARD 2	YARD 1	YARD 2
YEAR 1	1/$157.6M	1/$156.9M	1/$277.6M	3/$713.1M
YEAR 2	1/$176.9M	1/$166.1M	0/-	0/-
YEAR 3	1/$167.3M	0/-	1/$319.4	2/$578.4M
Expected Cost To Navy On Basis Of Bids = $2,713 Million Estimated Cost To Navy (With Growth in Buy-In Price) = $2,738 Million Estimated Cost to Navy of Buy-in = $25 Million				

Notes

1. Buy-In by Yard 1 on Ship Type 1 in Year 3.
2. Non-competitive allocation for Ship Type 1 in Year 2.
3. Non-competitive allocation for Ship Type 2 in Year 3.
4. Each entry in the table is of the form A/B, where A is the number of ships of that type allotted to the yard in that year, and B is the total cost to the Navy of these A ships in millions of dollars.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

This report documents the current state of the Navy Ship Acquisition Planning Tool, developed for the Naval Material Command Acquisition Research Council under contract with the Office of Naval Research. The report discusses the structure of the acquisition tool, and describes in detail its major modules: the ship cost module, the yard price module, and the optimization module.

The ship price module proceeds from the initial Navy estimate of manhours required to build the ship, along with the value of material to be purchased, subcontracts to be let, and the government-furnished equipment to be supplied to the shipbuilder. Special account is taken of features peculiar to a shipyard and a type of ship to refine the initial cost estimate, to take advantage of a more detailed appreciation of the factors contributing to the cost of building a ship. The yard price module translates this cost, along with the yard's economic objectives, into the price that the shipyard will bid to the Navy to deliver the ship. The price module also accounts for such peculiarities in the Navy-shipbuilder relationship as a shipyard which can build a ship relatively inexpensively bidding up its price because its only competition is a much less efficient shipyard. The effects of single-source procurement are included, as are the effects of buy-in. This is done by explicitly characterizing the auction market that exists in the Navy ship acquisition arena. Finally, the optimization

loop takes the prices that are bid to the Navy and chooses the set of procurements which meet Navy objectives over the term of the procurement period at the least cost to the Navy. All constraints facing the Navy in this procurement are accounted for. These include: the physical constraints existing at the shipyard (i.e., size and number of building ways, for example); constraints which might be termed strategic (i.e., the preservation of the capability to build major surface combatants on both coasts, for example); and finally, constraints which may be termed political (i.e., a particular shipyard may be required to participate in a particular program independent of its relative competitiveness with other candidate shipyards). One of the most important features of the optimization module is its ability to choose the lowest cost alternative in the face of constraints over a significant number of fiscal years; for example, five years, or even ten to twenty years. It does this, not by providing the lowest cost for each individual program, but by taking the Navy ship acquisition problem as an entity and optimizing over the entire multi-year plan.

An important feature of the acquisition planning tool is that it recognizes the commercial market existing in the United States shipbuilding industry. Commercial orders allow some shipyards to remain working with little or no Navy business. It is possible, in the future to extend this work to predict commercial business in the face of world economic conditions and the world shipbuilding market.

The ship acquisition planning tool has been assembled and demonstrated as a working tool. The next step is to validate this tool using data on the past Navy shipbuilding programs. This will allow pinpointing specific yard characteristics, and identifying variables which may be redundant in the ship acquisition planning tool as currently realized.

These data are shown in Chapter 4, as well as the place within the Navy where these data are available. The validation phase of the ship acquisition tool includes assembling the data in a useful form, not only for the ship acquisition planning tool, but for other studies which may be appropriate for guiding the Navy Acquisition Program. These data must be assembled if serious analyses of various alternatives are to be made using the ship acquisition planning tool as documented in this report, or indeed in any other way that is appropriate. Without these data, no meaningful analysis can be done which can lead to rational plans for the Navy's future ship acquisition plans.

Using the small amount of data available and simplistic estimates of shipyard characteristics, illustrative results have been provided. The model determines the least cost program for acquiring a given number of different types of ships in the face of not unusual constraints; such as, yard capacity and strategic requirements (i.e., keeping particular shipyards occupied). It has also shown how the addition of a constraint can change the cost of the lowest cost program, and therefore, shows how the ship acquisition tool can allow planners to evaluate the expected cost of any given constraint. Finally, the program was used to show how a buy-in can lead to increased costs over the optimum program without buy-in, and in fact, how the cost of the buy-in can be identified. In the course of these three examples, several other highlights have been shown and their significance discussed.

6.2 CONCLUSIONS

This report documents that the Navy ship acquisition tool can develop the lowest cost shipbuilding program in the face of various types of constraints; and it can show the cost

of individual constraints or constraints in concert. The ship acquisition tool can provide the Navy with a powerful and sophisticated means of optimizing their ship acquisition program over a given program period, whether it be one year, five years, or twenty years. It allows investigation in detail of a large number of constraints within a reasonable time at a modest cost. It can provide planners within the Secretariat, OPNAV, NAVMAT, and NAVSEA the ability to see beyond individual program optimization, and to make trade-offs between different shipbuilding programs. It can provide support for all decisions that the Navy Department proposes to the Defense Department, the Office of Management and Budget, and Congress. It can allow planners to reproduce results because the assumptions will be well documented. In summary, the ship acquisition planning tool promises to be a significant advance in Navy ship acquisition planning.

The major problem facing potential users of the ship acquisition planning tool is that necessary data have not been made available. This report has documented the data required, and has identified sources of these data within the Navy. With these data, the ship acquisition planning tool can be validated and implemented. The primary reason put forward for not making data available has been that gathering that much data will be difficult, and hence, expensive. The data identified must be collected and assembled into a useful form if any serious analysis is to be done, whether or not the Navy chooses to continue with this particular ship acquisition planning tool or to work with any other ship acquisition planning tool.

6.3 RECOMMENDATIONS

The Navy is now facing a proposed large rapid buildup in the Naval force structure and it must deal with the beginning

of this buildup in the face of a shipbuilding base which is in poor economic and technical health. The Navy, at present, has no planning tool with which to support the development of alternative programs. TASC's ship acquisition planning tool, along with all methods available or in prospect, can provide the necessary analytic support to assist Navy planners in making the proper choices.

The Navy has always and will always face difficult choices in shaping the future of the shipbuilding industry. Whether the issue be how to manage a significant buildup, or how to manage a small shipbuilding program while still maintaining the appropriate industrial base as a mobilization capability, a sophisticated, yet simple to use, planning tool is essential. The next step in the development of the ship acquisition planning tool is validation using a set of data available within the Navy. These data should be assembled not only to validate the ship acquisition planning tool but also to support the analyses of Navy shipbuilding programs.

> Recommendation 1 - Assemble a data base documenting performance of shipbuilders in serving the Navy's shipbuilding program.
>
> Recommendation 2 - Validate, refine and complete the development of the ship acquisition planning tool.

APPENDIX A

YARD COST ESTIMATION

The steps in the procedure for yard cost estimaton, as presented in the Ship Cost Model in TR-1337, have not been changed; modifications have been made, however, of the specific functional relationships used in the two principal equations: adjustment of the initial manhour estimate, and estimation of the yard overhead rate. This appendix describes the current procedure for yard cost estimation.

The procedure for estimating the cost of building a ship of a given type at a certain yard may be summarized as follows: the NAVSEA estimate of the basic manhours needed to build a given ship is adjusted for specific conditions at a given yard at a given time. The adjusted manhour estimate and average wage are used to find labor cost. Material and subcontract estimates, the effect of inflation, and the effect of the learning curve are combined with the labor cost to find the direct cost of the ship. Overhead costs are then computed and added to the direct cost to find the total yard cost for building the ship.

The actual number of hours of labor at yard i to build a ship of type j is different from the estimated (NAVSEA) baseline depending on the conditions existing in the yard at the given time. In addition, this manhour estimate changes year to year, reflecting the conditions in the yard during the particular procurement period. Thus, during a given procurement period, the manhour estimate is expressed as:

$$H = \frac{\beta_{1i} H_j^{o} (1+\beta_{2i} T+\beta_{3i} T^2)[\ell n(S_i + \beta_{4i})][1+\beta_{5i} (\frac{V_{ij}}{L_{ij} + V_{ij} + R_{ij}})] [1+ \beta_{6i} (\Delta M)^2]}{Y_i (A_{ij} + \beta_{7i})^{\beta_{8i}} (E_{ij} + \beta_{9i})^{\beta_{10i}}} \qquad \text{(A-1)}$$

where:

H_{ij} = predicted actual manhours at yard i in building ship j

H_j^{o} = baseline manhour prediction for ship type j

T_i = turnover rate at yard i during this procurement period expressed as the following fraction: (J + L - J - L)/2 (average annual employment at yard i); where J and L are, respectively, the number of workers joining and leaving yard i during this year

S_i = shift loading = 1 + (total no. of workers in shifts 2 & 3)/(total no. in shift 1)

R_{ij} = estimate of present cost of material supplied by shipyard i for ship j

V_{ij} = estimate of present cost of subcontracts which will be procured by yard i to build ship j

L_{ij} = initial estimate of present cost of labor to yard i for ship j

Y_i = labor window for yard i, as discussed below

A_{ij} = average time, in months, since hire of work force at yard i, at the midpoint of this procurement period

E_{ij} = average experience, in years, of first level supervision at yard i for the work force for ship j

ΔM_i = change in total employment of yard (number of workers) from previous year to current year

$\beta_{1i}, \ldots, \beta_{10i}$ = yard-specific parameters determined from historical yard data.

The yard "labor window", Y, recognizes that each yard has its own optimal employment level in which economies of scale can work to its advantage. At employment levels below this, lack of specialization and fixed costs start to make operation inefficient, while above this region the yard is not able to utilize its manpower efficiently due to overcrowding. The curve of Y_i is concave downward, and our representation is:

$$Y_i = 1 - \gamma_i (M_{oi} - M_i)^2 \qquad \text{(A-2)}$$

where:

Y_i = labor window at yard i during the current procurement period

M_{oi} = optimal employment level at yard i

M_i = actual employment at yard i during the current procurement period

γ_i = yard-specific factor.

In order to compute labor costs for the yard itself, all labor is grouped together and an average rate per yard is used. The adjusted direct labor costs are then given at yard i by

$$L^A_{ij} = H_{ij} W_i \qquad \text{(A-3)}$$

where:

W_i = hourly wage rate in yard i

H_{ij} = predicted manhours to build ship j at yard i.

The direct cost D_{ij} is then found from R_{ij}, V_{ij}, and L^A_{ij}, and depends on the time at which the ship is built and the experience with building type j ships:

$$D_{ij} = [\ L^{A}_{ij}(1+I_L)^t + R_{ij}(1+I_R)^t + V_{ij}(1+I_V)^t]\ (1+N_{ij})^{-\lambda_i} \quad \text{(A-4)}$$

where:

- I_L = labor inflation rate
- I_R = material inflation rate
- I_V = subcontract inflation rate
- N_{ij} = number of ships of type j previously built at yard i
- λ_i = learning curve coefficient for yard i (with λ_i>0 determined from historical yard data)
- t = a variable to account for effects of inflation. Clearly, t depends on the total time to build ship j: for example, t may be taken as half the time to build ship j.

Note that we have ignored the time elapsed between building the previous ships of type j at yard i. One might specify a cut-off point at which time previous experience is no longer considered valid. Also, it is clear that this formula would not hold for large values of N_{ij} (since $N_{ij}^{-\lambda_i} \to 0$ as N_{ij} increases), but the fit is expected to be good for the smaller N_{ij}'s associated with ships. This will not give the usual learning curve values since several of the effects normally attributed to learning are explicitly included in our direct cost equation. Rather it will be a yard specific value based on the cumulative data base from the specific yard.

The next step is to compute the overhead cost O_{ij} associated with building ship j at yard i. We express this as

$$O_{ij} = \dot{O}_{ij}D_{ij} + F_{ij} \quad \text{(A-5)}$$

where:

$\dot{O}_{ij}$ = overhead rate for yard i at the time of building ship of type j

F_{ij} = exceptional fixed investment, if any, by yard i for ship of type j by yard i.

F_{ij} represents any fixed investment which must be made in yard i when a ship of type j is to be build there for the first time. This cost is allocated completely to the first ship rather than being spread over several ships of the same type. If the ship is to be built early in a plan period, the fixed investment will probably be written off over the plan period. If the ship is to be built later, then this costing procedure may cause an overestimation (if, in fact more ships of type j are to be built <u>after</u> the five-year period) but it is anticipated that this error is self-correcting by changes in later yearly replanning allocations.

We may write

$$F_{ij} = F^{\circ}_{ij}\ (1 + I_F)^t \qquad \text{(A-6)}$$

where:

F°_{ij} = estimate of F_{ij} in the present year for yard i and ship j

I_F = inflation rate for capital investments

t = projected time at which special equipment will be expensed.

The equation for overhead rate $\dot{O}_{ij}$ is based on historical observation of its relation to yard conditions and is given as:

$$\dot{O}_{ij} = \alpha_{1i} + \alpha_{2i}B_i + \alpha_{3i} \frac{R_{ij}}{R_{ij} + V_{ij} + L^A_{ij}}$$

$$+ \alpha_{4i} \frac{V_{ij}}{R_{ij} + V_{ij} + L^A_{ij}} + \alpha_{5i}S_i$$

B_i = backlog of yard i during the current procurement period

$\alpha_{1i},\ldots,\alpha_{5i}$ = yard-specific parameters determined from historical yard data

L^A_{ij}, R_{ij}, V_{ij}, S_i are as defined earlier.

Once the overhead cost has been computed for the specific conditions in yard i, the total yard cost is computed as:

$$YC_{ij} = D_{ij} + O_{ij}$$

where:

YC_{ij} = total cost of building ship j at yard i

D_{ij} = direct cost to yard i of building ship j

O_{ij} = overhead cost of yard i for building ship j.

APPENDIX B

ESTIMATING YARD PRICES AND COSTS TO THE NAVY FOR A GIVEN ALLOCATION

For a given allocation, an auction market framework is used to determine yard prices and the ensuing cost to the Navy. The implemented auction market is shown in Figures B-1 and B-2. The yard bid prices are determined on the basis of the yard objective. We assert that

$$MNYP_{ij} = AYC_{ij}\ (1 + RR_{ij} \cdot YO_{ij}) \qquad \text{(B-1)}$$

where:

$MNYP_{ij}$ = minimum acceptable bid price for yard i for ship j

AYC_{ij} = average cost to yard i for building ship j

YO_{ij} = 0 = yard objective of maximizing cash flow

YO_{ij} = 1 = yard objective of maximizing return on investment

RR_{ij} = minimum rate of return acceptable to yard i for ship j.

For any negotiated price in the auction market, the price charged to the Navy is the minimum acceptable bid plus a negotiated fee. In the competitive bid, the yard with the lowest MNYP bids at a level between its own MNYP and the next lowest MNYP among other competing yards. Thus, the winning bid for ship j is:

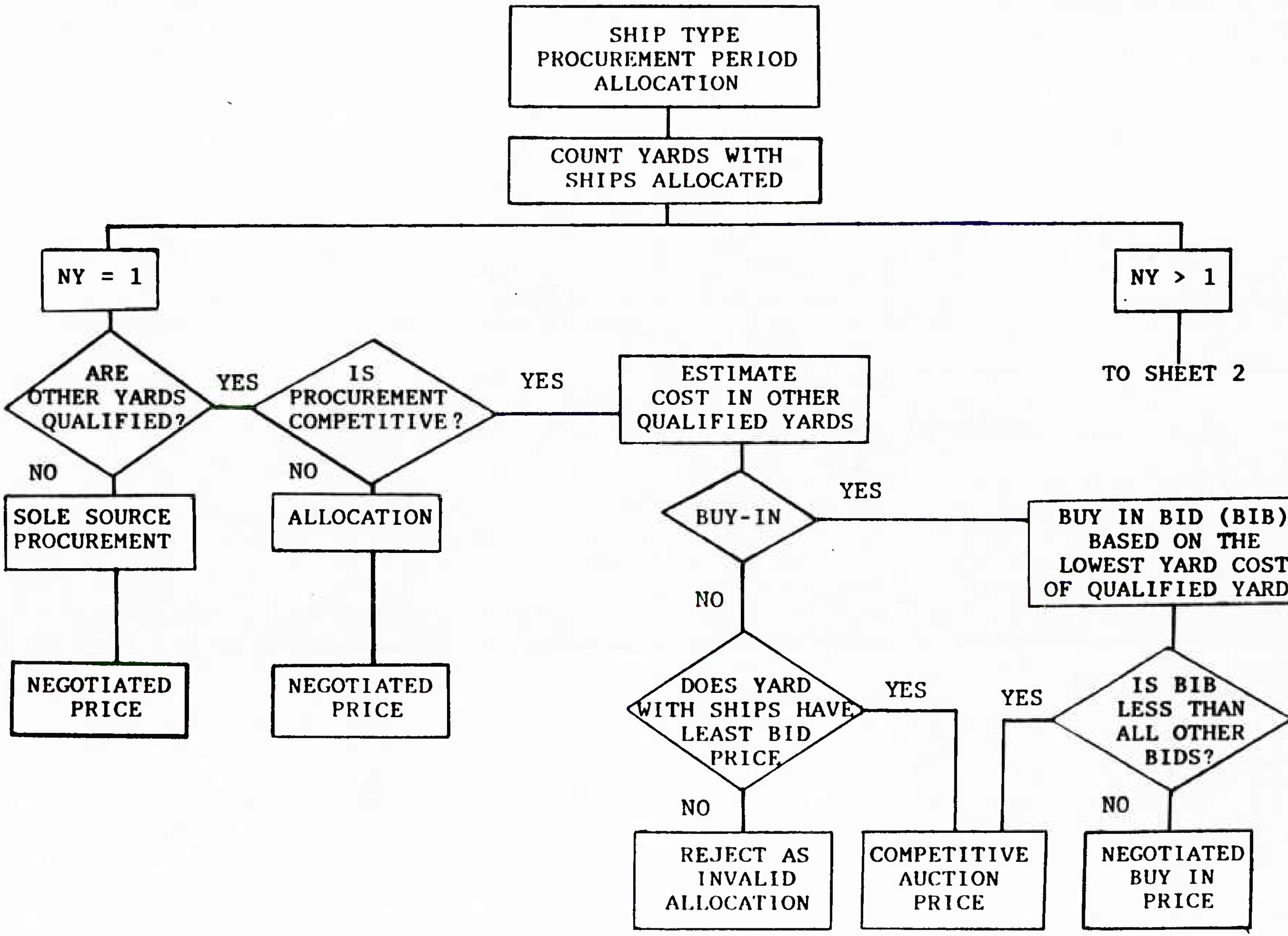


Figure B-1 AUCTION MARKET - PART 1

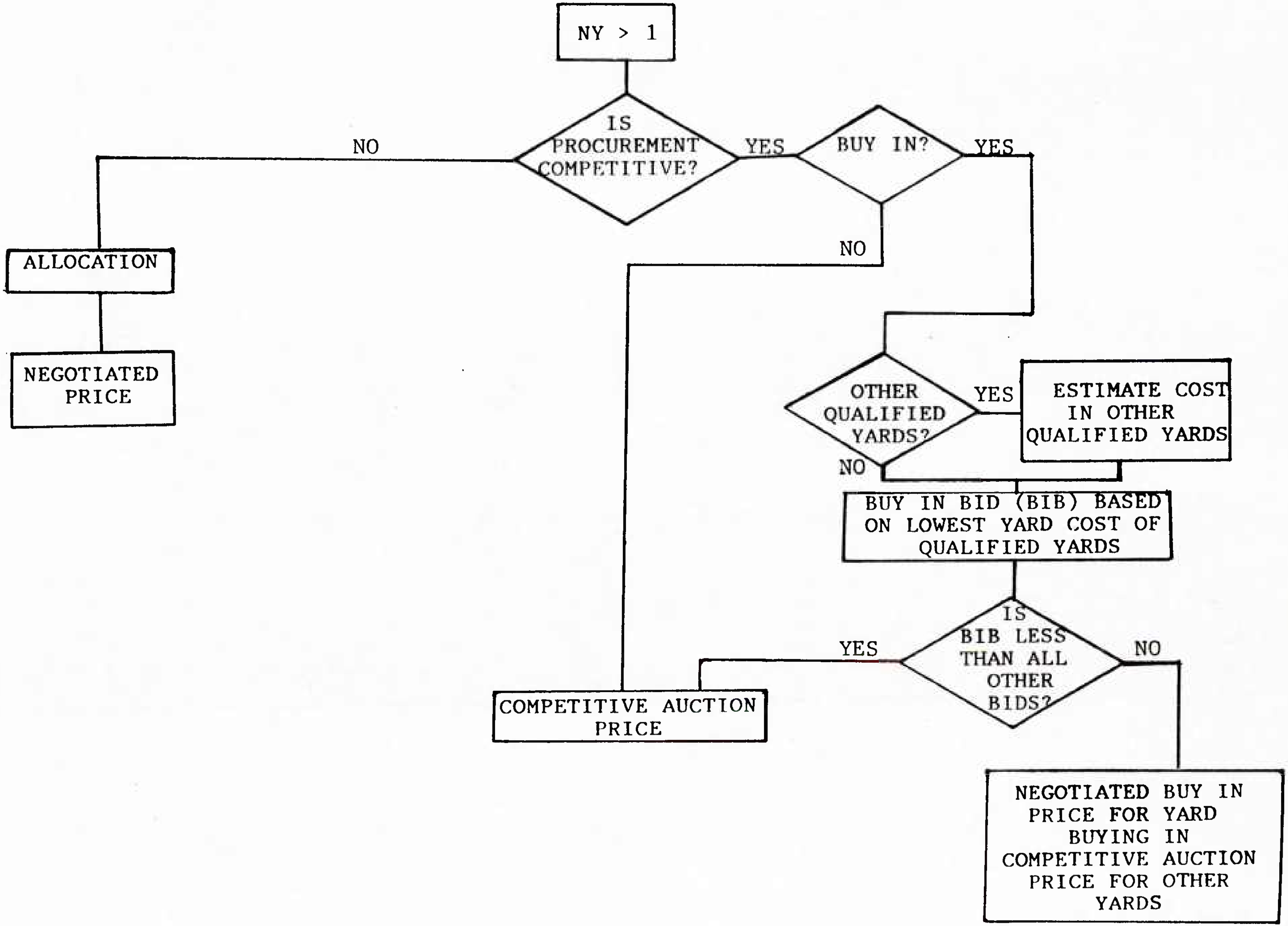


Figure B-2 AUCTION MARKET - PART 2

$$WINP_j = MIN_j + Z_j\ (NMIN_j - MIN_j) \qquad \text{(B-2)}$$

where:

$WINP_j$ = the winning bid in the competitive auction

MIN_j = the lowest MNYP for ship j among all competing yards

$NMIN_j$ = the next to lowest MNYP for ship j

Z_j = factor between 0 and 1 determining winning bid at level higher than MIN_j and lower than $NMIN_j$.

Finally, the total costs to the Navy are computed by including GFE and administrative costs:

$$CN_{ij} = YP_{ij} + G_j + U_j \qquad \text{(B-4)}$$

where:

CN_{ij} = total cost to the Navy of building ship j in yard i

YP_{ij} = the price charged by yard i for ship j, either through competitive or through non-competitive procurement

G_j = cost of GFE furnished by Navy

U_j = costs to Navy not directly related to building process (administrative, testing, etc.).

G_j and U_j are taken as given quantities, for the present year. The only expressions concerning their values are:

$$G_j = G_j^o(1+I_G)^{t_1} \qquad \text{(B-5)}$$

$$U_j = U_j^o(1+I_U)^{t_2} \qquad \text{(B-6)}$$

where:

G_j^o = estimate of G_j if built at the present time

U_j^o = estimate of U_j^o if done at the present time

I_G, I_U = inflation rates of GFE and administrative category

t_1, t_2 = times at which these costs are actually incurred.